Environmental Assessment of Groundwater Condition in Tarout Island, Eastern Province of Saudi Arabia.

BY

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THESIS ABSTRACT

NAME: **RAEID HUSSAIN AL SADEQ**

TITLE OF STUDY: **ENVIRONMENTAL ASSESSMENT OF GROUNDWATER CONDITION IN TAROUT ISLAND, EASTERN PROVINCE, SAUDI ARABIA**

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In this study, the quality of groundwater in Tarout Island of eastern Saudi Arabia was investigated and evaluated. To achieve this objective, samples collected from surface water, shallow and deep groundwater wells were analyzed. The analysis shows that the deep groundwater in Tarout Island is not suitable for drinking purposes due to the existence of elements with concentration higher than the maximum allowable limit. The majority of samples collected from a shallow subsurface showed a high concentration of nitrate, nitrite, aromatic hydrocarbons, and some heavy metals such as lead. The study indicates that leaks from industrial waste and domestic sewers as well as the underground septic tanks, are commonly being experienced in most of the study area. An individual risk map for each parameter which exceeded the standard limit was created. A comprehensive map for environmental risk level was also developed. The majority of the parameters (iron, manganese, copper, nitrate, sulphate and cyanide) at most sampling stations are within the permissible limits specified in the water standards guidelines.

MASTER OF SCIENCE
KING FAHD UNIVERSIYU OF PETROLIUM & MINERALS
DHAHRAN, SAUDI ARABIA

ملخص الدراسة

الاسم رائد حسين الصادق

عنوان الدراسة تقيم جودة المياه الجوفية في جزيرة تاروت واثر المخاطر البيئية عليها

التخصص علوم البيئة

التاريخ يناير- 2011

اعتمدت هذه الدراسة في تقييم جودة المياه الجوفية في جزيرة تاروت، شرق المملكة العربية السعودية على محاولة الربط بين نوعية المياه الجوفية والأنشطة البشرية في جزيرة تاروت. وقد تم جمع و تحليل عدد من العينات من المياه السطحية والمياه الجوفية الضحلة والمياه الجوفية العميقة ، وأظهرت نتاج التحليل أن المياه الجوفية العميقة في جزيرة تاروت ليست مناسبة لغرض الشرب بسبب وجود بعض العناصر بتركيز أعلى من الحد الأقصى المسموح به حسب المعايير ال دولية. وأظهرت الدراسة بأن غالبية العينات التي تم جمعها من المياه الضحلة وجود بعض العناصر مثل النترات والنتريت و الهيدروكربونات العطرية و الرصاص بتركيز فاق الحد المسموح به. وعزت الدراسة وجود هذه العناصر والمركبات وبنسب مختلفة الى تجميع النفايات الصناعية في أماكن غير مخصصة لهدا الهدف والى التسرب الناتج من مياه الصرف الصحي . وقد تم إنشاء خريطة بيئية تبين توزيع هذه العناصر والتي تجاوزت الحد القياسي على خريطة منطقة البحث كما تم إعداد خريطة شاملة لمستوى المخاطر البيئية. وقد بينت الدراسة أيضا أن غالبية العناصر مثل الحديد والمنغنيز والنحاس و النترات والكبريتات والسيانيد في معظم العينات تقع ضمن الحدود المسموح بها و المحددة في معايير المياه المعمول بها دوليا.

CHAPTER 1

INTROUDUCTION

1.1 General

Saudi Arabia is one of the fastest growing countries in the region. Industrial development includes mainly crude oil and gas, petrochemical, and agriculture. In line with this development, population growth rate and urbanization has also increased. Residential development of urban areas has become an important land-use issue in Saudi Arabia. It has a direct effect on the available natural resources. One of the main resources, which are highly affected by urbanization, industrial and agricultural developments, is the ground water resource.

Saudi Arabia is located in a semi-arid region with limited rainfall rates. The average rainfall is estimated at 25-152 millimeter, except in the southwest, where average annual rainfall is 508 millimeter (PME, 2009). The renewable freshwater resources are limited. As a result, water availability has become a major issue of concern in Saudi Arabia. Water resources in the kingdom are: groundwater, desalinated sea water, and reclaimed waste water. The rates of water withdrawn exceeds natural recharge rates which mean that water demand is much higher than water supply (Abderrahman, 1995).

To overcome the water shortage and to meet its increasing water demand, Saudi Arabia resorted to several measures such as desalination of sea water, reuse of treated municipal wastewater,

especially in agriculture, and water conservation. Water quality has also become another major issue in the Kingdom. Clean water availability may be affected due to the pollution caused by industrial wastes, sewage systems and agricultural fertilizers. Groundwater quality and availability are two important challenges for the sustainability of water resources in Saudi Arabia.

1.2 Study Area: Tarout Island

1.2.1 Geographic Location

Tarout Island is located on the west Coast of the Arabian Gulf in a flat stretch of coast on Tarout Bay, east of Qatif city and north of Dammam city (Figure 1). This island covers an area of about 30 km^2 of the coastal line. The area lies approximately on the intersection of longitude 50.3^o E and latitude 26.35^oN. It is bounded by the Arabian Gulf from all directions. Tarout is linked to Qatif from the west by a causeway (Figure 1).

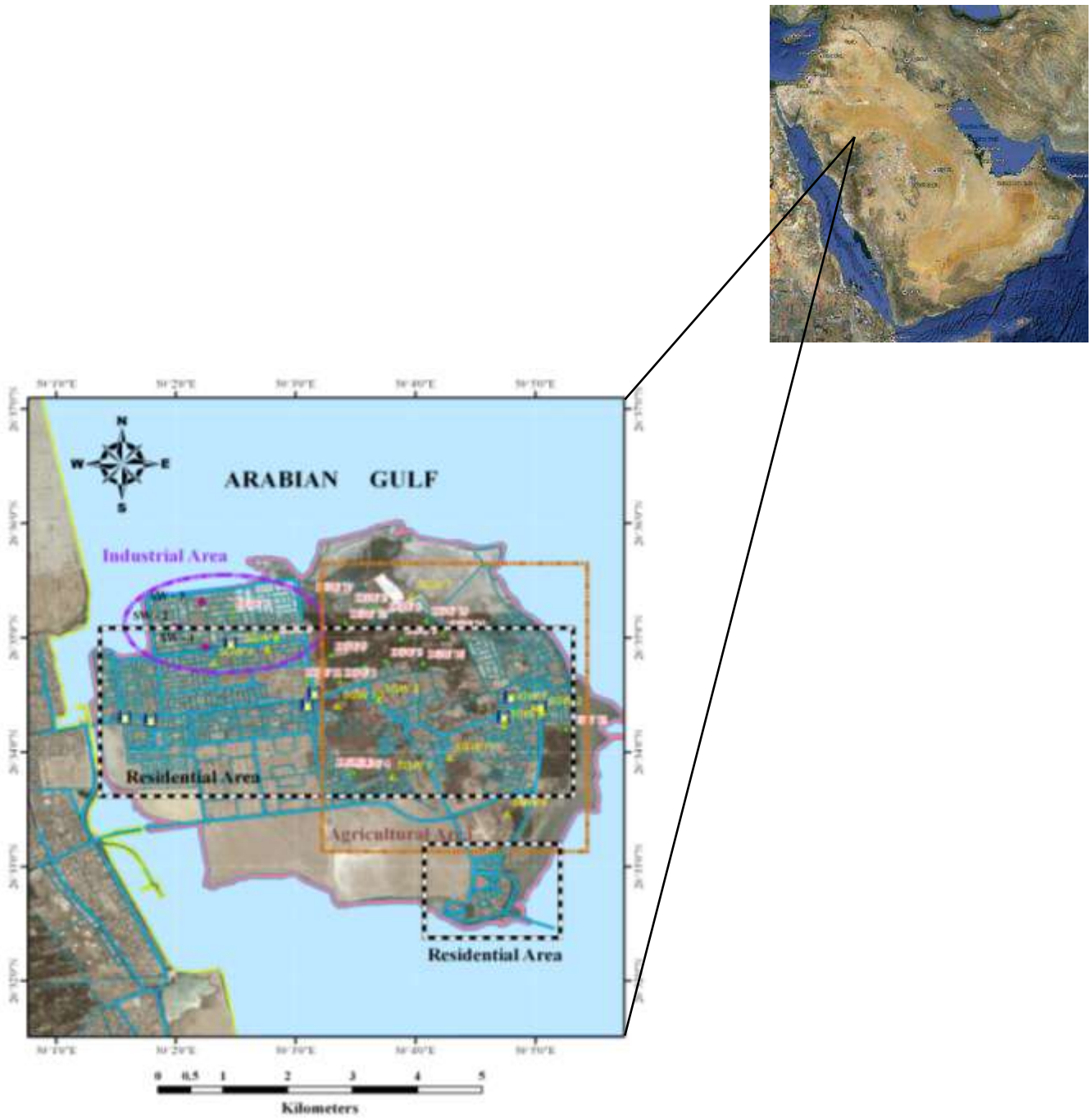


Figure 1: Location map of the study area

1.2.2 Climate

The climate in Tarout, similar to the climate of the Eastern Coastal Region in the Eastern Province of Saudi Arabia, is characterized by high temperatures, high evaporation rates, and high relative humidity in summer. The temperature in summer exceeds 45^{O}C. It reached 49^{o}C in 1980 (Ramis, 2006). However, the temperature in winter drops down to 5^{O}C. The humidity is very high in Tarout. In 1990 it was 100% (PME, 2009).

1.2.3 Precipitation

The average and extreme rainfall in Dammam between 1982 and 2005 is shown in Figure 2. The amount of rainfall varied significantly over this period. Between 1928 and 1994, this fall was gradual. It decreased sharply from 200 mm in 1982 to 10.5 mm in 1994. However, over the next six years the rainfall increased gradually to about 187 mm in 2000, then the amount of rain felled by 2005 to 1 mm (PME, 2005).

1.2.4 Land Use

Tarout Island consists of many suburbs including: Old Tarout, Sanabes, Al-Rabayiah, Daren, Al-Dhakel, Al-Munera, and Turkia. Most of these suburbs are located along the coast. The total population was 101,171 in 2004 (Central Department of Statistics & Information, 2004). The population growth rate in Tarout Island is shown in Figure 3.

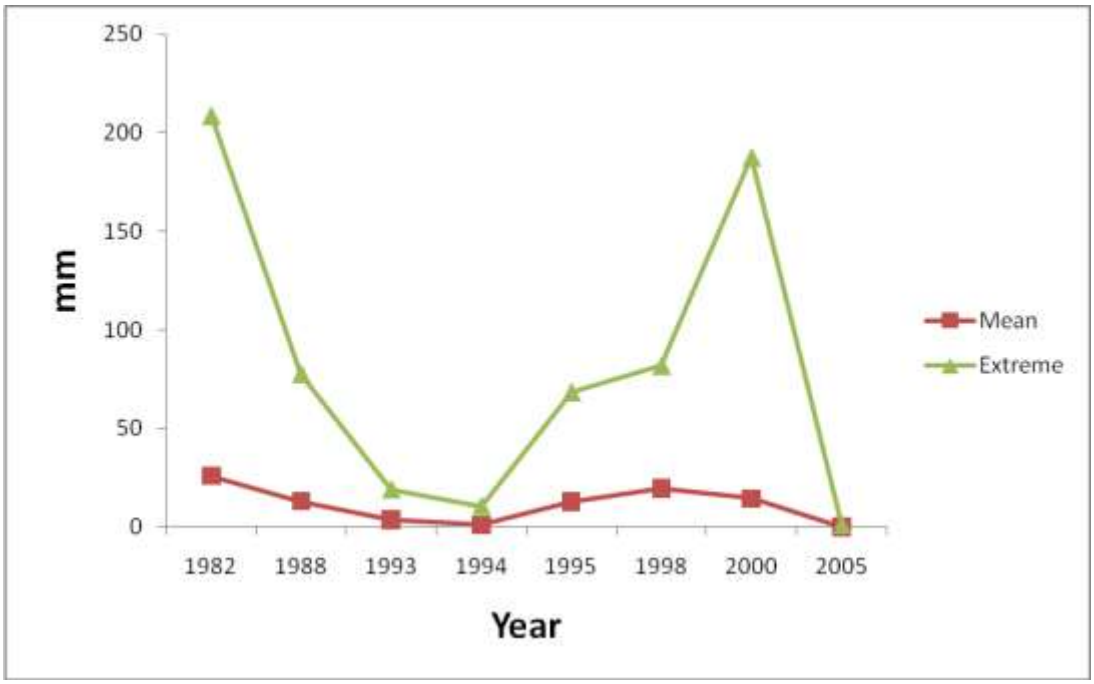


Figure 2: Average and maximum annual rainfall rates in Dammam between 1982-2005 (PME, 2005)

Sanabes and Al-Rabayiah suburbs in the central and eastern parts of Tarout Island are characterized as being the agricultural areas and suburbs which include Turkia in the northern part of Tarout; an industrial area. The western part (Dhakel and Al-Munera) is the residential area.

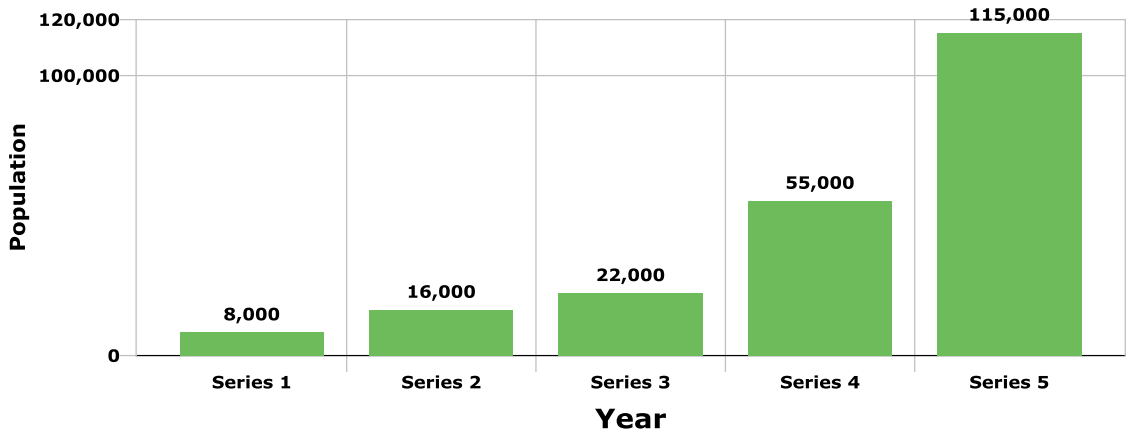


Figure 3: Population growth in Tarout Island from 1908 to 2004 (Ramis,2004)

On the other hand and as a result of urbanization the agricultural area has been reduced to 2 million square meters in 2005. Figure 4 shows the decline in the green land from 1940 to 2005 (Ramis, 2004).

According to Ramis (2004) the green land has decreased from 6 million square meters in 1940 to 2 million square meters in 2005 and the urbanization has increased to 10 million and 600 thousand square meters as indicated in Figure 5. The relationship between the decline in green land and the increase in urbanization is an inversely proportional relationship.

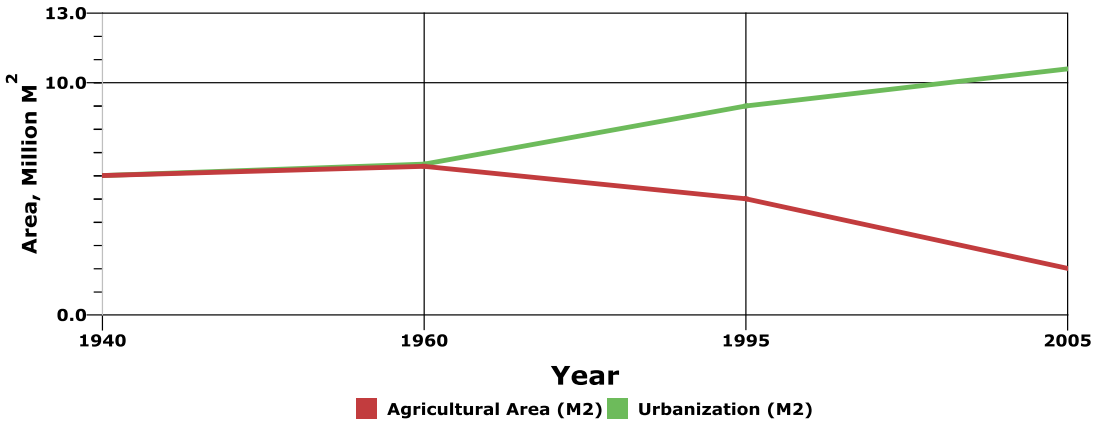


Figure 4: The decline in green land in Tarout Island from 1940 to 2005 (Ramis,2004)

1.2.5 Urbanization and Water Issue

Tarout Island is a good and representative example of the water situation in the kingdom. The large increase in population growth rate, rapid development of residential areas and the expansion of industrial activities in Tarout Island is expected to pose an environmental risk on the available natural resources. One of the main resources that is highly susceptible to environmental risks is the groundwater. As a result of the urbanization, industrial and agricultural development, water demand in Tarout Island has increased dramatically in the last three decades. Tarout Island depends mainly on groundwater for its domestic and agricultural activities. There are no other alternative sources of water on the island. The availability of water from the main groundwater wells is not always secured on a daily basis.

Tarout Island area increased from 15 Km^2 in 1940 to more than 30 km^2 in 2005 (Figure 5) due to reclaim process (Ramis, 2006).The majority of houses do not have a sewage network and people depend on septic tanks for sewage disposal. The septic tanks are constructed using traditional methods. Contaminants from such septic tanks may reach groundwater aquifers. Time may pass before a contamination result from an improperly designed septic tank system is detected. Outdated septic tank systems are a source of groundwater contamination. Organic and inorganic compounds including Biological Oxygen Demand (BOD), Chemical Oxygen Demand (COD), nitrates, nitrites, ammonia, and phosphorous are among the main contaminants of groundwater resources.

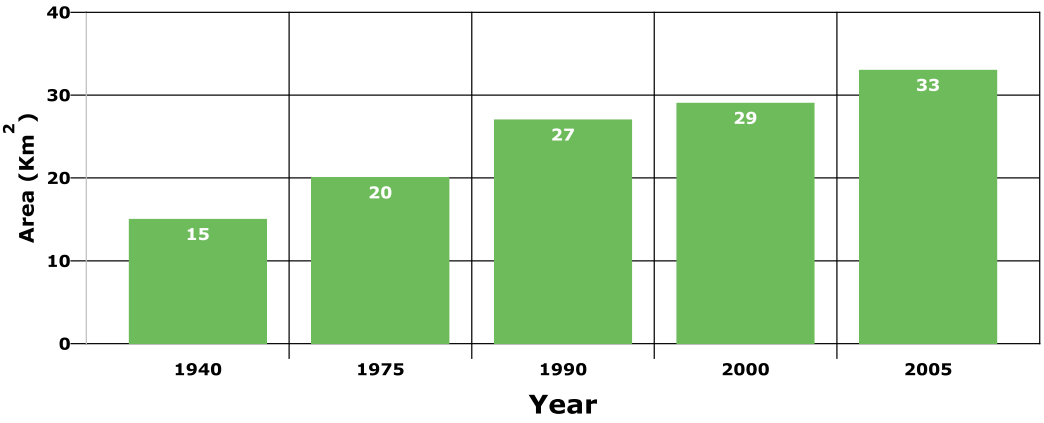


Figure 5: Tarout land area expansion from 1940 to 2005

As a result of urbanization in Tarout Island and rapid increase in population, some industrial activities such as mechanical workshops, automobiles workshops, plastic industry, and aluminum workshops have been inflated. All workshops in Tarout Island and in Qatif city, in eastern Saudi

Arabia have been shifted to the industrial area in Tarout which is called Turkia. This area may act as another source of pollution of the environment and of the groundwater.

The problems associated with groundwater in Tarout Island can be summarized as follow:

- Uncontrolled over-pumping of groundwater due to lack of awareness and the increased number of residential and irrigation wells.
- Deterioration of water quality due to leached sewage from septic tanks and leachates from municipal, agricultural, industrial activities, , and landfills.

CHAPTER 2

OBJECTIVES

The overall objective of this study is to assess the groundwater quality conditions in Tarout Island. The specific objectives are:

1. To study the effects of industrial activities, infiltration of municipal wastewater from septic tanks, leachate from agricultural activities on the groundwater quality.

2. To calculate the environmental risk index (IER) for elements exceeding the allowable limits.

CHAPTER 3

LITERATURE REVIEW

3.1 Geological Setting of Tarout Island

The study area is one of the historical coastal cities in the Eastern Province of Saudi Arabia. Coastal cities of the Eastern Province such as Al-Khobar, Dammam, and Qatif depend mainly on groundwater from the Khobar and Alat aquifers for domestic, irrigation and industrial purposes (Abderrahman et.al, 1995). Tarout Island hydrology was not included in the study by Abderrahman et.al (1995), but can be inferred from the study due to Tarout Island proximity. The following discussion on the geology and hydrogeology of the study area is obtained from the work conducted by ITALCNSULT,1969; BRGM, 1977;, and GDC, 1980.

Since Khobar and Alat members are the main source of groundwater to the coastal belt cities including Tarout, the geological features of these two members and some geological information and physical properties will be presented in the next sections.

3.1.1 Dammam Formation

The Dammam formation crops out at the circumference of the Dammam Dome and in four smaller batches about 10km to 25km to the west of the dome (Johnson, 1978). It conformably

overlies the Rus formation and is bounded at the top by Eocene-Neogene unconformity. It mainly consists of carbonates with intercalation of shale and marls.

The Dammam Formation is subdivided into five members from bottom to top:

1. Alat Member
2. Khobar Member
3. Alveolina Limestone Member
4. Saila shale Member
5. Midra shale Member

Khobar and Alat members are the main aquifers in the coastal belt cities.

3.1.2 Khobar Member

The Kohbar aquifer comprised of two units: a lower units: and an upper unit which are called Khobar marl and Khobar limestone, respectively. The lower unit consists of 1.5m of light gray to 10m dolomitic marl. The upper unit consists predominantly of limestone (with 4m of light gray, partly recrystallized, non porous, nummulitic limestone). Above this is 1m of yellowish-brown, soft marl limestone, which is overlying 3m of yellowish gray, massive, hard, nummulitic, calcarenitic limestone (Al Sayyari and Zottle., 1978).

The general composition of Khobar aquifer near the bottom consists of skeletal detrital limestone, dolomite limestone, and argillaceous. It is bounded at the top by orange Marl of Alat ,and at the bottom by Alveolina limestone (Abderrahman, 1995).

3.1.3 Alat Member

Similar to the Khobar member , the Alat Member is divided into two units; the upper unit consists predominantly of limestone and the lower unit is composed mainly of marls. The lower unit is called Orange Marl or Alat Marl. At outcrops, the Alat Marl consists of 6m of light-colored dolomitic marl. The upper unit is composed of 9m of cream, chalky, porous, commonly dolomitic limestone with numerous molds of mollusks (Johnson, 1978). Large variations in the thickness are observed due to the Pre-Neogen erosion. At the type section, the thickness is 15m.

3.2 Hydrology of Tarout Island

The hydrogeological studies carried out by companies like ITALCNSULT. (1969); BRGM, (1977); and GDC (1980), described the aquifer system in the Eastern Province of Saudi Arabia (Table 1) . The studies show that the system has three main aquifers separated by semi-confined beds. They are from bottom to top: the Umm Er Radhuma (UER) aquifer, the Rus confining bed (including the Midra and Saila Shales and Alveoline limestone members), the Khobar aquifer, the

Alat aquitard and Alat aquifer. The coastal cities of the Eastern Province such as Tarout Island extensively use the Khobar and Alat aquifers for domestic and irrigation purposes.

A brief discussion of each aquifer is given in the following paragraphs. More focus will be given to Khobar and Alat aquifers since they are the ones feeding Tarout Island with groundwater sources.

3.2.1 Khobar Aquifer

The Kohbar aquifer is a member of the Dammam formation. The general composition of Khobar aquifer near the bottom consists of skeletal detrital limestone, dolomite limestone, and argillaceous. It is bounded , at the top, by Orange Marl of Alat, and at the bottom by Alveolina limestone. The transmissivity values vary from area to area. It was 0.009 to 0.29 m^2/s near the Qatif Oasis and $5.7 * 10^{-6}$ m^2/s to $5 * 10^{-4}$ m^2/s in Al-Hassa area (Hassan,1992).

The storativity value was 2.1×10^{-5} which indicates the confined nature of the aquifer (Rasheeduddin, 1988). The average depth below ground level is 100m with the maximum depth being 241m at Ras Tanura and the minimum being zero near Dhahran. It is absent at the top of the Dammam Dome where the member is eroded (Italconsult ,1969; GDC. 1980). Personal communications with the drillers and well owners confirms that the depth of most of the wells in the study area range from 80 m to 150 m.

3.2.2 Alat Aquifer

This aquifer consists of skeletal, deterital and dolomitic limestone. The depth below ground level ranges from zero at the Dammam Dome to 123m at Ras Tanura. However the average depth is 25m (ITALCONSULT, 1969). The transmissivity value of Alat aquifer range from 3.1 x 10^{-4} m^2/s to 2.6 x10^{-4} m^2/s (Abderrahman et.al.,1995). The storativity value was 2.1 x 10^{-5} which indicates the confined nature of the aquifer. However, near the erosional surface at Dammam dome, the Aquifer shows its semi confined to unconfined behavior: the thickness variation ranging from 20m to 110m (Rasheeduddin, 1988).

At this point it is very useful to illustrate and describe a hydrogeologic system in Tarout Island by developing a hydrogeologic cross sections of the study area. The east-west cross section (Figure 6) was constructed using a combination of information, including well logs and stratigraphic data collected from the water authority at Dammam. It is starts from East Qatif, crosses the Gulf and ends in east of Tarout Island.

Age		Formation or equivalent	Member or equivalent	Thickness	Description of formation and lithology	Hydrogeology
Quaternary		Superficial deposits		Very variable, generally less than 30 m	Aeolian sands, wadi-fill deposits, sheetwash deposits, alluvial deposits and sabkhah deposits.	Wadi-fill deposits contain localized groundwater. Sabkhas are areas of natural groundwater discharge. Sand dunes induce recharge locally.
Tertiary	Miocene–Pliocene (Neogene)	Al-Hofuf		10–30 m at Al Hassa	Marl with limestone intercalations of fluviatile sands and marls in upper parts.	Poor, unconfined, aquifer generally but locally along major wadis may form a more productive aquifer.
		Dam		0–100 m	Hard, compact microlitic limestone ranging from chalky to marly facies. Extensive fissuring and karstification in the upper part of the formation. Fissures frequently sand-filled.	Excellent aquifer around Al Hassa. Little known elsewhere.
		Hadrukh		25–90 m at Al Hassa	Clean sands at the base followed by marly sands, siltstones and sandy microlitic limestone. Large lateral facies variations are characteristic.	Excellent aquifer in Al Hassa, especially basal sands. Little known elsewhere.
	Eocene	Dammam	Alat limestone	15–50 m	Light-covered limestone of varying hardness. Chert bands in top part common.	Moderate aquifer.
			Alat marl	10–20 m	Marl, with characteristic light reddish brown ("orange" in literature) colorations.	Aquitard where present.
			Khobar limestone	20–45 m	Light-coloured, crystalline limestone, locally fissured Calcarenitic and dolomitic facies occur at Al Hassa.	Aquifer.
			Khobar marl	5–15 m	Mainly marl, with subordinate shales and thin limestone layers.	Aquitard where present.
			Alveolina	Up to 15 m	Thin limestone interbedded with marls or shales.	Complete section forms an aquitard.
			Saila-Midra	5–10 m	Dark-coloured shale. Eroded or missing over small areas of the Ghawar anticline.	Aquitard where present.
		Rus		40–200 m where anhydrite is present; 20–30 m in the absence of anhydrite	Chalky limestones, anhydrites, dolomitic limestone and shales.	Aquitard.
	Palaeocene	UER		250–600 m increasing from west to east	Limestones and dolomites in varying proportions with anhydrite facies. Locally karstified and infilled with argillaceous sediments. The centre of the aquifer is primarily calcarenitic. Limestones, frequently fissured, and this grades downwards into dolomitic facies and more argillaceous limestones with shale/marls at the base.	Aquifer. Calcarenitic facies constitute an excellent aquifer, particularly if fissuring is well developed. Fine-grained and anhydritic facies constitute a very poor aquifer. Basal shales form aquitard between UER and Aruma. Dolomitic zones are only moderate aquifer if fissured.
Cretaceous		Aruma		400–600 m	Limestones and shaley limestones are dominant lithologies, with proportion of shales generally increasing in depth.	Poor aquifer.

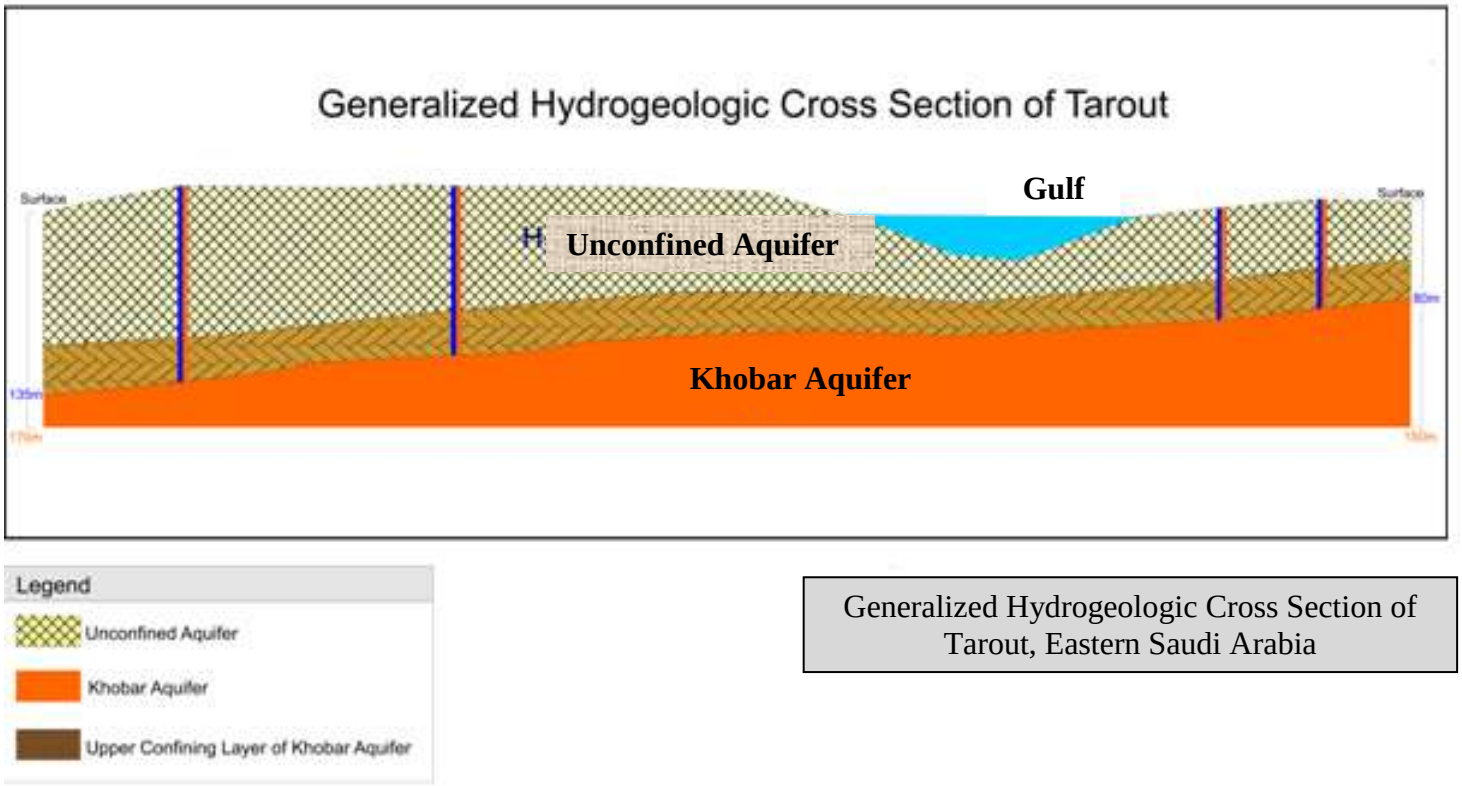
Table 1: Hydrogeological Characterization of the strata in the study area (after Backiewicz et al., 1982)

This cross section was developed based on the data extracted from wells such as the well location, depth of well, and the lithostratigraphic. With reference to data collected from Water Authority at Dammam ,wells are commonly drilled to depths of 80 to 150 of meters in Qatif and 80 to 170 of meters in Tarout Island penetrating the Khobar aquifer. The wells depth in Tarout Island varies from area to another. While it is 80 meters in the west, it reaches 150 meters in the central area and again it is reduced to 80 meters at the costal site.

3.2.3 History of Ground Water Extraction

The extraction rate from Alat and Khobar aquifers (Figure 7) along the coastal belt of Arabian Gulf in the Eastern Province was about 49.3 MCM in 1967 (ITALCONSULT, 1969). In 1990 , the withdrawal rate increased to 101 MCM and 326 MCM from Alat and Khobar aquifers respectively (Abderrahman, 1990). The Alat and Khobar aquifers are the main suppliers of water to the townships along the coastal belt of the Arabian Gulf such as Dammam, Qatif, Saihat and Anak (Abderrahman, 1995). Tarout Island was not discussed in that study but since it is very close to these cities, the same argument can be applied. Coastal cities of the Eastern Province such as Al-Khobar, Dammam, and Qatif depend mainly on groundwater from the Khobar and Alat aquifers for all purposes (Abderrahman, 1995).

More than ten wells have been drilled in Tarout Island since 1974 by the Water Authority in Eastern Province to meet the rapidly increasing water demands. As a result of rapid increase in population, the demand on groundwater has also increased. Unavailability of water in most of new lands forces people to drill many private wells in their properties. The extraction records indicate a continuous increase in extraction rates since 1940 and marked upward trend after 1965 (Groundwater Development Consultants, 1980).



Generalized Hydrogeologic Cross Section of Tarout, Eastern Saudi Arabia

Figure 6: Hydrologic cross section of Tarout Island

Table 2: Comparison between the Distribution of Hydrochemical Constituents in Alat and Khobar Aquifers (Hassan, 1992).

Parameter	Jubail Area		Qatif-Dhahran		Abqaiq-Al-Hafuf	
ppm	Alat	Khobar	Alat	Khobar	Alat	Khobar
Calcium	400-1100	500-1000	300-500	300-500	200-300	200-500
Magnesium	160-420	260-420	100	100-180	60-80	60-80
Sodium	1000-5500	1000-5000	400	500-1100	400	500
Chloride	> 5000	>5000	500-1000	900-1700	500	500
Sulfate	1000-2000	700-1600	600-1600	600-1600	400-600	400-1300
Bicarbonate	150-180	160	140-180	160-200	210-500	200-500
TDS	>1000	>1000	2000	2000-4500	>2000	2000-3000

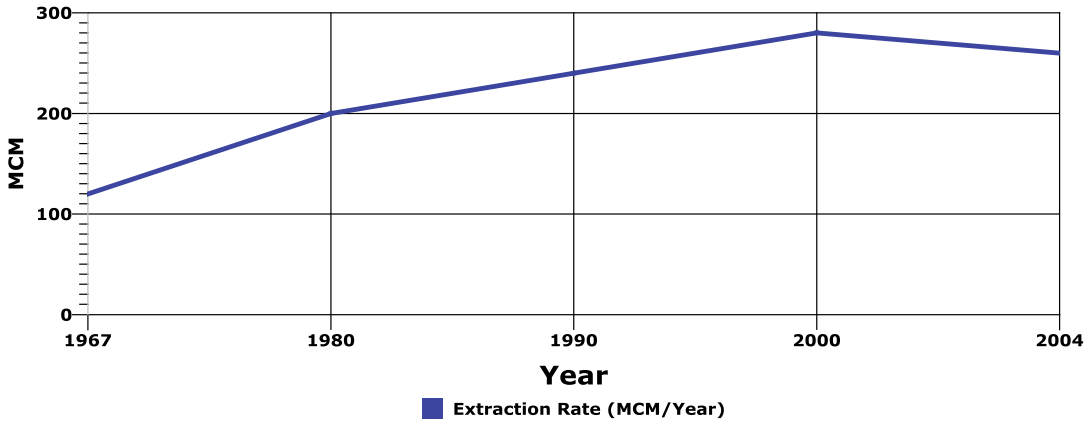


Figure 7: Annual pumping rate from Alat and Khobar aquifers in million cubic meter per year.

The simulated drawdown contour maps for different aquifers in the Eastern Province are shown in Figure 8 (Abderrahman, 1995). In the Alat aquifer, the drawdown map in Figure 8 shows a localized cone of depression in Qatif including Tarout Island to the north of Ras Tanurah due to extensive water pumping. The decline in water level from 1978 to 2000 was about 14 m (Abderrahman, 1995). In Khobar aquifer and due to low transmissivity values and the small thickness of the aquifer, the drawdown in Qatif was about 5 m in 2000 (Abderrahman, 1995).

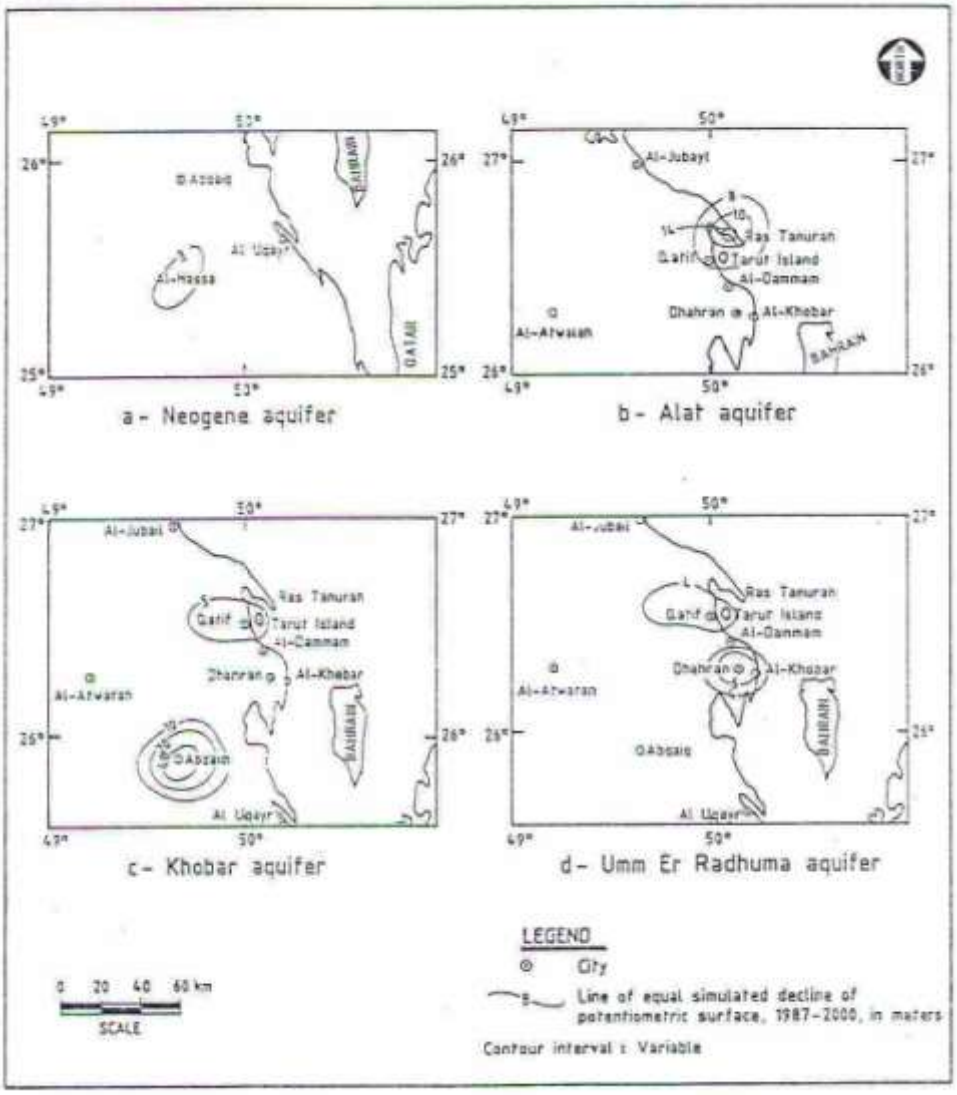


Figure 8: Simulated decline of the poteniometric surface in various aquifers (Abderrahman,1995).

3.2.4 Hydrochemistry

The hydrochemistry data of Dammam aquifer is listed in Table 3 (Rasheeduddin 1999) . The sodium content ranges between 90 and 3410 ppm at Al-Jafurah and Al-Fadhli respectively with high values at Tarout Island. The calcium was 114 ppm at Al-Jafurah and 1275 ppm at Abu-Hadriyah. The calcium content at Tarout Island was 266 ppm. Magnesium at Tarout Island was 87 ppm. The higher value of magnesium (433 ppm) was found at Al-Jafurah and the lower value (5 ppm) was found at Ras Tannurah. Chloride ranges between 181 and 6816 ppm, at Abu Ali and Al-Fadhli respectively.

The chloride concentration in Tarout Island was 1052 ppm. The maximum value of carbonate (520 ppm) was found at Abu Ali and the minimum value (140 ppm) at Ras Tannurah. Carbonate concentration at Tarout Island was found 174 ppm. Sulphate ranges between 398 ppm at Ayn Dar and 1531 ppm at Al-Fadhli. The Sulphate content at Tarout Island was equal to 475 ppm. Total dissolved solids (TDS) was found in the range of 852 ppm and 13241 ppm at Al-Jafurah and Al-Fadhli respectively.

TDS in Tarout Island was about 2870 ppm. The general trends of the TDS in Dammam aquifer can be derived from the distribution of TDS in Figure 9. The TDS concentration increases towards the Arabian Gulf with the exceptions at and around Dammam dome (Rasheeduddin 1999). The contour of 12000 ppm covered a large distance in the area. As per the conclusion of the study by Rasheeduddin 1999, the piezometric heads are falling drastically along the coast with the present heads at 2-3 m above sea level. If lateral intrusion of sea water would occur, the salinity could have reached more than 10,000

ppm starting at Jubail-Qatif belt. There were no such indications during the survey made for data collection (Rasheeduddin 1999). Therefore, high salinity cannot be attributed to saline intrusion. The only possible reason is the lithology in this region. The major ion concentration in Dammam Aquifer is shown in piper diagram in Figure 10. Also it can be attributed to the controlled flow of groundwater towards the sea and slow movement of water horizontally and vertical flows to Sabkahas (Figure 11).

Table 3: Major Ion concentration in groundwater of Dammam Aquifer. (Rasheeduddin, 1999).

Sample ID	Sample Location	Concentration (mg/l)							
		Na^+	K^+	Ca^+	Mg^{++}	Cl^-	HCO^-_3	SO^-_4	TDS
1	Wadi Al-Miyah	371	24	226	104	756	161	519	2108
2	Ayn Dar	288	17	181	64	562	202	398	2853
3	HOFUF	196	14	234	72	344	175	714	1667
4	Manifah	2798	90	848	431	6468	257	779	11869
5	Jubail	390	14	227	94	848	198	452	2236
6	Abu Hadriyah	2800	43	1275	423	6690	184	1457	12872
7	Al-Jafurah	90	9	114	46	213	144	283	852
8	Al-Fadhli	3410	80	794	433	6816	177	1531	13241
9	Qatif	449	20	225	84	887	175	525	2373
10	Ras Tannrah	312	19	339	5	875	140	226	1947
11	Abu Ali	270	25	323	111	181	520	974	2403
12	Shadgam	550	27	245	49	860	408	535	2692
13	Al-Uqayr	1370	39	427	198	2395	164	1374	5953
14	Uthmaniyah	352	25	120	54	626	198	284	1662
15	Dammam	616	34	285	96	1255	225	501	2445
16	Al-Khobar	552	61	238	87	1144	166	505	2690
17	Abqaiq	801	28	353	113	1309	147	1053	3713
18	Fazran	452	52	117	45	717	153	450	2030
19	Tarut	490	54	266	87	1052	174	475	2870

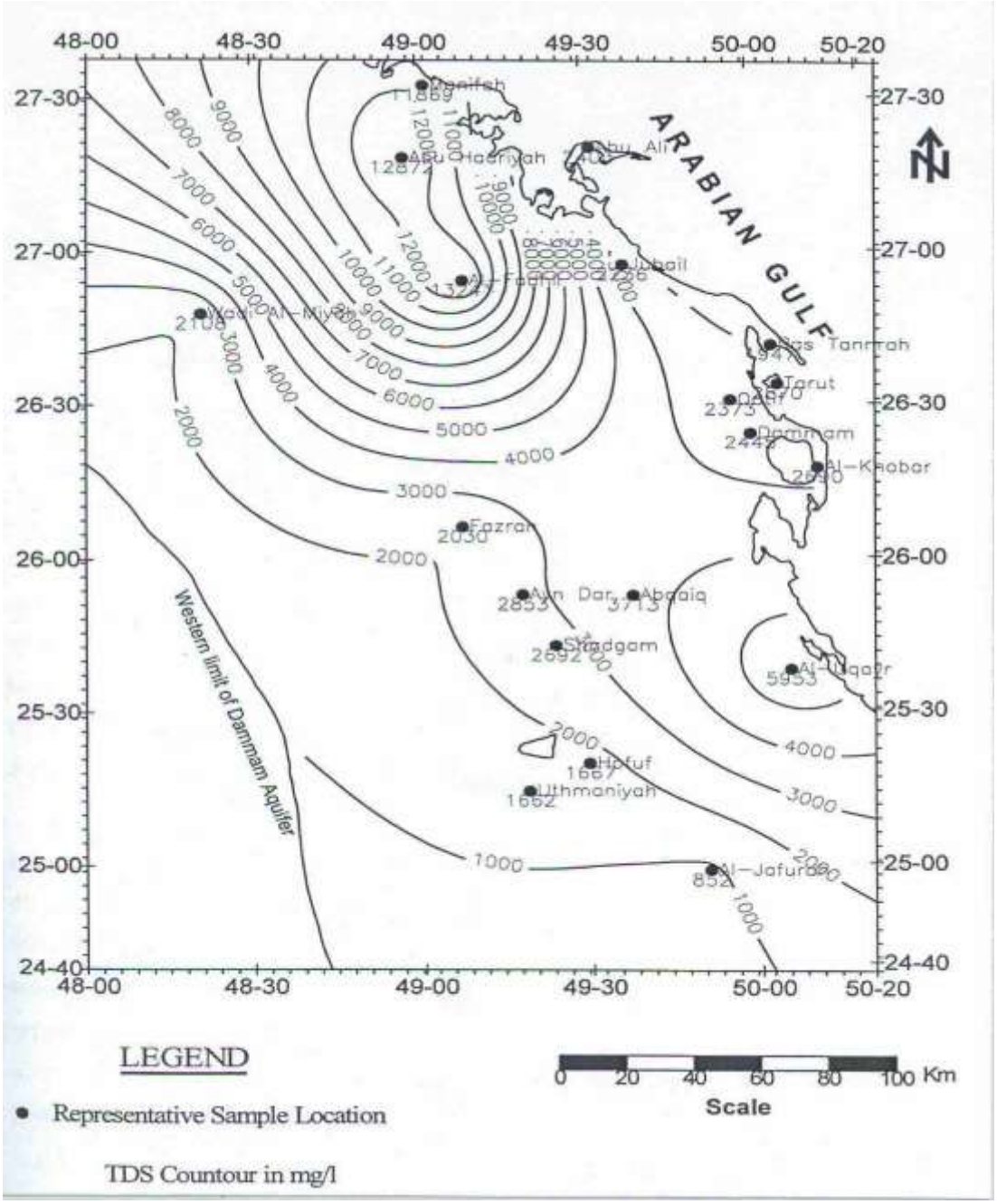


Figure 9: Distribution of Total Dissolved Solids (TDS) in Dammam Aquifer (Rasheeduddin, 1999).

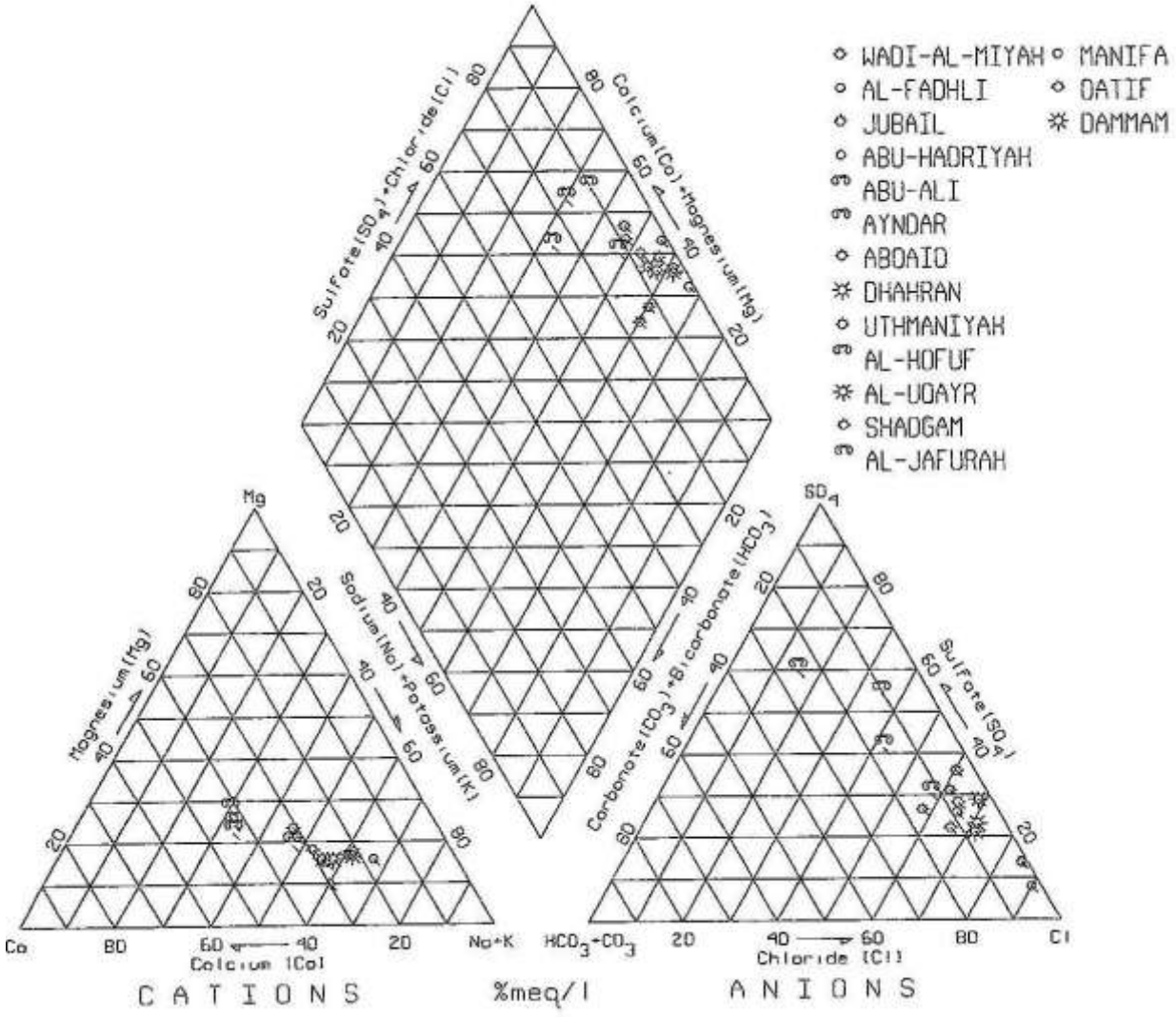


Figure 10: Piper diagram showing major ions concentration in Dammam Aquifer (Rasheeduddin, 1999).

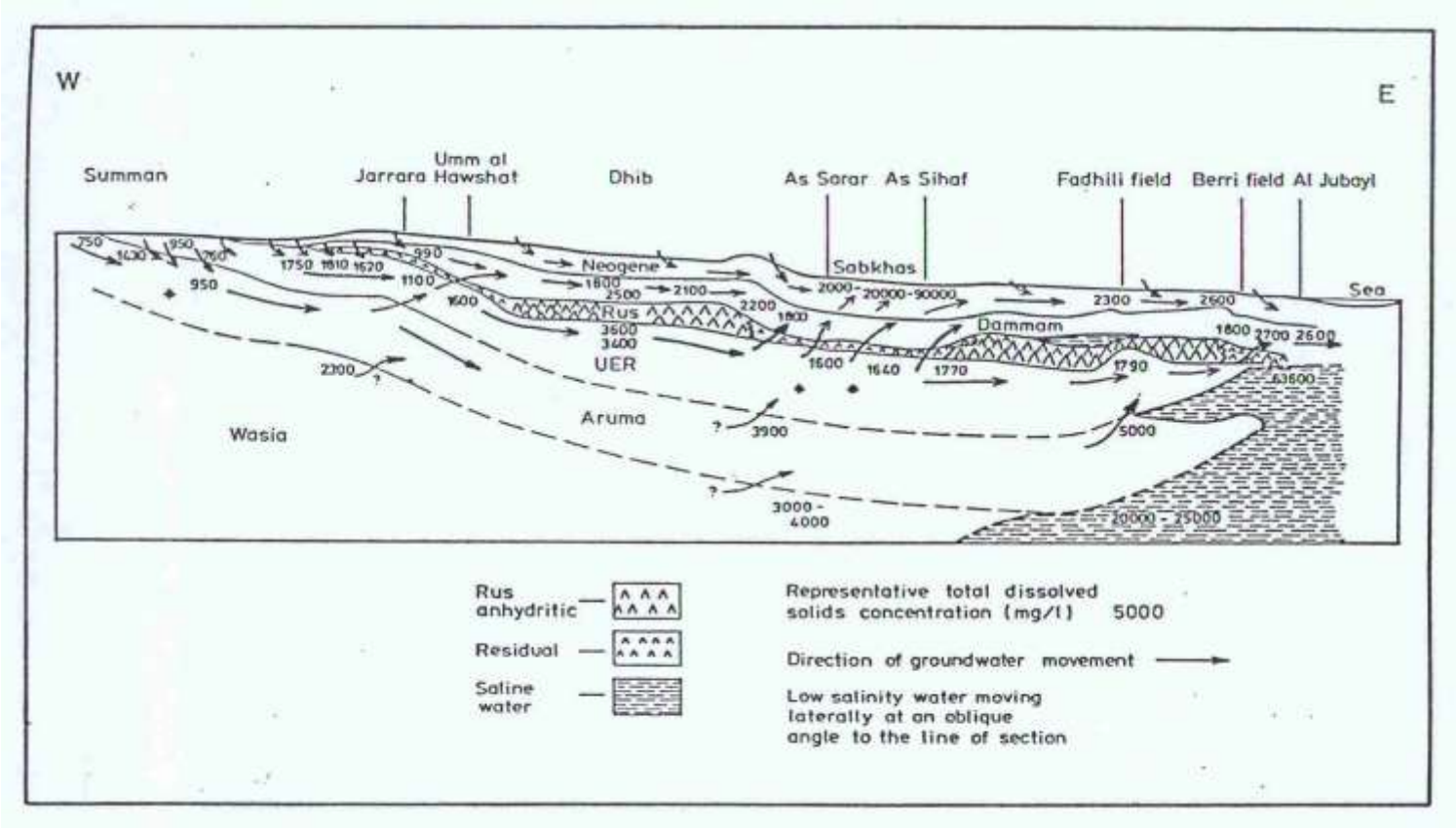


Figure 11: Groundwater flow and salinity, a schematic diagram in a multi-aquifer system in eastern Saudi Arabia (After Bakiewicz et al., 1982)

3.3 Impacts of Urbanization on Groundwater System

The effect of urbanization on groundwater systems is one of the critical topics discussed around the world. This is because in many cases, groundwater is the primary source of drinking water. The links between the groundwater, surface water and land use is an important element of the urban hydrologic cycle (Mudd et.al., 2004). Land utilization is considered as one of the important features in every urbanized area (Douglas, 1983; Foster and Lawrence, 1996). Leakage from water and wastewater infrastructure impacts the quality of the groundwater and affects the recharge-discharge behavior of groundwater (Mudd et.al., 2004).

In developed areas the groundwater recharge is more numerous and difficult than in rural areas (Lerner, 2002). It depends on a large amount of water supplied and distributed through underground pipes which is collected again in sewers or septic tanks. Several studies have been done to determine the amount of leakage but the difficulties to identify the pathways of recharges in urban areas make the accurate estimation very hard (Lerner et.at., 1990).

Leakage from sewers and septic tanks in urban areas can contaminate groundwater with nitrate. (Powe & Schepers, 1989). The impacts of urban area on groundwater quantity are primarily twofold, either decreasing due to abstraction impacts on an aquifer storage or increasing due to seepage and leaks. Quality of groundwater in urban areas is affected by several sources which can include in developed countries industrial, pipe infrastructure,

land use and so on. The contamination includes heavy metal, nutrients, pathogens, and salts (Fetter, 2001). In the last 25 years, the massive urbanization development causes depression in the water table (Ishaq, et.al., 1995).

Reclamation as a result of urban expansion, especially along the coastal areas causes several problems to the groundwater. Studies on the impacts of reclamation of the groundwater regime were ignored because of the slow and unobvious changes in groundwater regime (Jiao, 2000). The first study which discusses the variation of water table associated with land reclamation is done by Mahmood and Twigg (1995). They conclude water table rises are limited to areas reclaimed by the sea, together with a slim coastal strip in the reclamation places. Later, study carried out by Jiao (2000) proposes other problems associated with reclamation, the reclamation increases the groundwater flow path to the sea. Reclamation reduces the groundwater discharge towards the coast by blockage of major submarine discharge zone.

3.4 Sources and Types of Groundwater Contamination

Several studies have been done on the groundwater contamination sources and types. The important attributes to be considered in any study dealing with groundwater contamination sources are: (1) contamination degree of localization which is described by point and non point sources, (2) their loading history which describes the contamination release rates and concentration variation as a function of time, and (3) the types of contaminants being released from them (Domenico and Schwartz,1998).

In general, the human activities and natural processes are the main sources of groundwater pollution. The former is the industrial and agricultural activities. The latter is the salt water intrusion (Taha et al., 2004). Solid and liquid waste disposal are also considered as a main factor for groundwater quality deterioration (Mangore and Taigbenu, 2004).

Singh et al. (2006) studied the quality of groundwater in the Gangetic alluvium plain, India and found high phosphate, chloride, nitrate, and sulphate contents near an area with intensive agricultural and industrial activities. Melian et al. (1999) tested the quality of groundwater in Balatina and Carbineni areas in Turkey and observed a very poor quality drinking water where intensive agricultural activities existed. Another groundwater contamination investigation was done by Ahn and Chon (1999) for Asan agricultural zone and Gurogu industrial and residential area in Korea. The study found concentrations of NO_3^-, Cl^-, and TDS above the permissible limits which were regulated by World Health Organization (WHO, 1998) and Turkish Standards Institute (TSE 2005) for drinking water. The study found that the NO_3^- concentration is high in the agricultural region. The study also attributed the high content of Cl^- to the lack of a sewage system and waste water discharge from industries into the Fetrek River.

Elhatip et al. (2003) investigated the quality of groundwater in Incesu-Dokuzpinar springs in Turkey and found high concentrations of NO_3^- , Na^+ and Cl^- . Researchers mentioned that the reason behind this contamination is the sewage and agricultural wastes in the area. Another study done by Umar and Ahmad (2000) in the Ganga basin, India shows the concentrations of heavy metals such as Fe, Mn, Cd, Pb and Cr^{+6} were higher than the allowable limit and the reason was the household refuse, sewage and industrial effluents.

Ibe Sr and Abgamu,1997 indicate that the groundwater in the alluvial is being polluted from various sources: infiltration from Warri River and irrigation channels; municipal wastewater infiltration from septic tanks; agricultural activities; gasoline tanks, toxic chemicals and hydrocarbon. Potential sources of Ground Water Contaminations are listed and categorized in Table 4

An investigation carried by The College of Agriculture in King Saud University on the chemical characteristics and bacterial contamination in Buraydah, Saudi Arabia, found that the chemical analysis for water quality of most of the wells showed high to very high salinity (TDS of 512-1664 ppm), high concentrations of Cd and Pb (0.2-0.47 and 0.5-31.0 ppm respectively). Eleven wells were contaminated ; 4 with both either Escherichia coli or salmonella sp. The total bacterial count in various wells ranged from 10 to $4.6x10^4$ cfu/ml (Abdelmomen, et.al., 1990).

Table 4: Potential Sources of Ground Water Contamination, EPA

No	Contamination Sources	No	Contamination Sources
1	Gas stations/service stations	40	Improperly functioning septic tanks
2	Agricultural chemicals, fertilizer,	41	Dry cleaners
3	Truck terminals	42	pesticides spreading/spraying
4	Oil pipelines	43	Fuel oil distributors/storage
5	Body shops	44	Auto repair shops
6	Auto chemical suppliers/	45	Rustproofers
7	Pesticide/herbicide/insecticide	46	wholesalers/retailers
8	Small engine repair shops	47	Wholesalers/Retailers
9	Painters/finishers	48	Furniture strippers
10	Printers	49	Photographic processors
11	Laundromats	50	Car Washes
12	Medical/dental/veterinarian offices	51	Beauty salons
13	Food processors	52	Research laboratories
14	Concrete/asphalt/tar/coal	53	Meat packers/slaughterhouses
15	Treatment plant lagoons	54	companies
16	Stormwater impoundments	55	Railroad yards
17	Airport maintenance shops	56	Cemeteries
18	Airport firefighter training areas	57	Airport fueling areas
19	Machine shops	58	Industrial manufacturers
20	Heat treaters/smelters/descalers	59	Metal platers
21	Chemical reclamation sites	60	Wood preservers
22	Industrial waste disposal sites	61	Boat builders/refinishers
23	Municipal wastewater treatment	62	Wastewater impoundment areas
24	Landfills/dumps/transfer stations	63	plants and land application areas
25	Subdivisions	64	Junk/salvage yards
26	Heating oil storage(consumptive	65	Individual residences
27	Golf courses/parks/nurseries	66	Sand and gravel mining/other
28	Mining	67	Abandoned wells
29	Manure piles/other animal waste	68	Feedlots
30	Agricultural chemical storage sites	69	Construction sites
31	Transportation corridors	70	Fertilized fields/agricultural areas
32	Petroleum tank farms	71	Existing wells
33	Nonagricultural applicator sites	72	Sinkholes
34	Recharge areas of shallow and	73	highly permeable aquifers
35	Injection wells	74	Drainage wells
36	Waste piles	75	Materials stockpiles
37	Animal burial sites	76	Open burning sites
38	Radioactive disposal sites	77	Salt-water intrusion
39	Mines and mine tailings		

CHAPTER 4

MATERIALS AND METHODS

4.1 Sampling and Analysis Plan:

A sampling plan was designed for sample collection, preservative, and analysis in order to assess the water quality. The sampling plan includes the following:

- Selection of sampling location
- Sample collection procedure
- Analysis of Samples

4.1.1 Selection of Sampling Location

The sampling locations were selected to cover most of the study area and a special concern was given to the critical areas which are very close to the possible contamination sources. To carry out the assessment of ground water quality, samples were collected from different types of water media starting from water above the ground to the deep groundwater aquifer through the surface water. Twenty three (23) samples were collected from the deep aquifer. In addition, three (3) samples from the surface ponds during the rainy season in dumping areas in the industrial region in (Turkia), eleven (11) samples from shallow groundwater about 5-6 meters deep from different areas. Wells locations are shown on the map in Figure 12. Sampling points were identified as follow:

- SW: samples collected from surface water.
- SGW: samples collected from shallow groundwater
- DGW: samples collected from deep groundwater.

4.1.2 Samples Collection

Water samples collection took place over a two week period. Collection of data was performed as per the standard procedures set by EPA (US EPA, 2003)

4.1.3 Samples Analysis

pH, temperature, electrical conductivity, and total dissolved solid (TDS) were measured in situ using multi function measurement electrodes. At SABIC Technology Center Laboratory anions (chloride, bromide, nitrate, nitrite,) and cations (Sulfate, phosphate, sodium, potassium) were measured using ion chromatography (IC). Heavy and trace metal were measured using Induced Coupled Plasma Mass Spectrometry (ICP-MS). Table 5 shows the details of the main instruments used in samples analysis.

Bacterlogical analyses were performed at The Royal Commission laboratory at Jubail, in the Eastern Province of Saudi Arabia. Total coliform analysis was measured in the water samples using Presence-Absence (P-A) procedure. This provides a qualitative result of contamination.

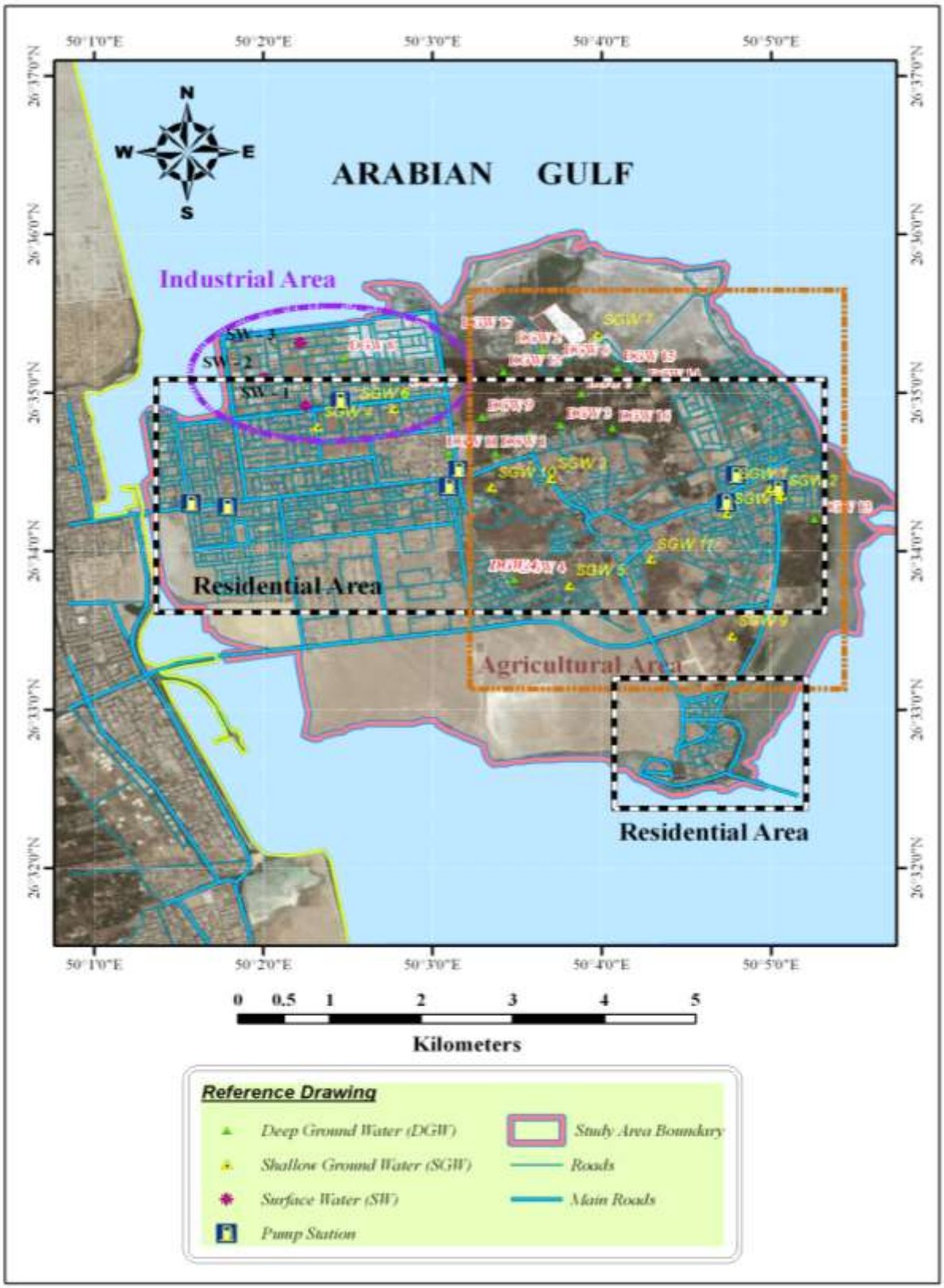


Figure 12: Location of water samples collected from the study area

Durham's tubes were used to mix five ml sample and 5ml brilliant green bile (2%). The tube was vacuumed and put into incubation for 24h at 35^{o}C. Oxygen got preserved inside the tube on the basis of the presence of bacteria in the sample. After that the tubes were kept for incubation for 24h, and 48h to identify the presence of coliform.

All the samples were preserved and carefully transported to the laboratory. The analysis was performed in accordance with ASTM, USEPA, and Standard Methods for the Examination of Water and Wastewater (Table 6).

Table 5: Main Instruments Used in samples analysis

Instrument Name	Description
IC	Ion Chromatography (Dionex model DX-500) including an injection valve, a sample loop, guard column, separator column, and a membrane suppressor enclosed in a LC 20 chromatography module.
ICP-MS	Inductively Coupled Plasma-Mass Spectrometer with octapole reaction system and equipment operating software (MS ChemStation). Equped with Auto sampler, integrated sample introduction system (ISIS) with auto diluter, Organic solvent kit for wear metals in lubricating oils and hydride generation system for the precise analysis of metals that generate stable hydrides like arsenic, selenium, mercury etc.
GC-MS	Gas Chromatograph (Agilent 6890) and Mass Spectrometer MSD 5973 with turbo pump, and MSD Productivity ChemStation software. Equiped with Purge & Trap Liquid Sample Concentrator (Takmar LSC 3100)

4.2 Creating Contour Maps

ArcGis software was used to develop a spatial analysis of all measured parameters of groundwater analyzed samples. Spatial maps were created by using ArcGIS ,version 9. The comprehensive set of Spatial Analyst tools within ArcGIS allows us to explore and analyze the data and enables us to better understand the relationship between the elements distribution and the contamination source. This was done by following the steps below:

1. Study location map was added to the ArcGis.
2. Data frame layers for location of wells, aquifer type and types of features were created within the ArcGis software.
3. An individual layer for every element was created.
4. The data layers were added to the location map.
5. A map for each element was created showing the spatial distribution of the concentrations over the study area.

4.3 Correlation Analysis

Each sample was analyzed for different parameters and linked to the probable source of contamination. The relationship between the contamination sources and the contaminants is shown in the flowchart in Figure 13.

Table 6: Standard Methods for the Examination of Water and Wastewater

Parameters	Instruments	Method	References
pH	pH meter	Electrometric	ASTM D1293
TDS	TDS meter	Instrumental	Standard Method for examination of water and waste water 2540C
Conductivity	Conductivity Meter	Instrumental	EPA 413.2
Chemical oxygen demand	COD Reactor	Instrumental	Standard Method for examination of water and waste water 20th edition 1998
Biological oxygen demand	BOD reactor	BOD	Standard Method for examination of water and waste water 20th edition 1998
Bromide	IC Spectrometer	Instrumental	ASTM D4327
Chloride	IC Spectrometer	Instrumental	ASTM D4327
Fluoride	IC Spectrometer	Instrumental	ASTM D4327
Nitrate	IC Spectrometer	Instrumental	ASTM D4327
Nitrite	IC Spectrometer	Instrumental	ASTM D4327
Phosphate	IC Spectrometer	Instrumental	ASTM D4327
Sulfate	IC Spectrometer	Instrumental	ASTM D4327
Calcium	IC Spectrometer	Instrumental	ASTM D4327
Magnesium	IC Spectrometer	Instrumental	ASTM D4327
Sodium	IC Spectrometer	Instrumental	ASTM D4327
Heavy Metals	ICP-MS	Instrumental	ASTM D6800-02
Aromatic Hydrocarbon	Hydrocarbon GCMS	Instrumental	EPA Method 524.2

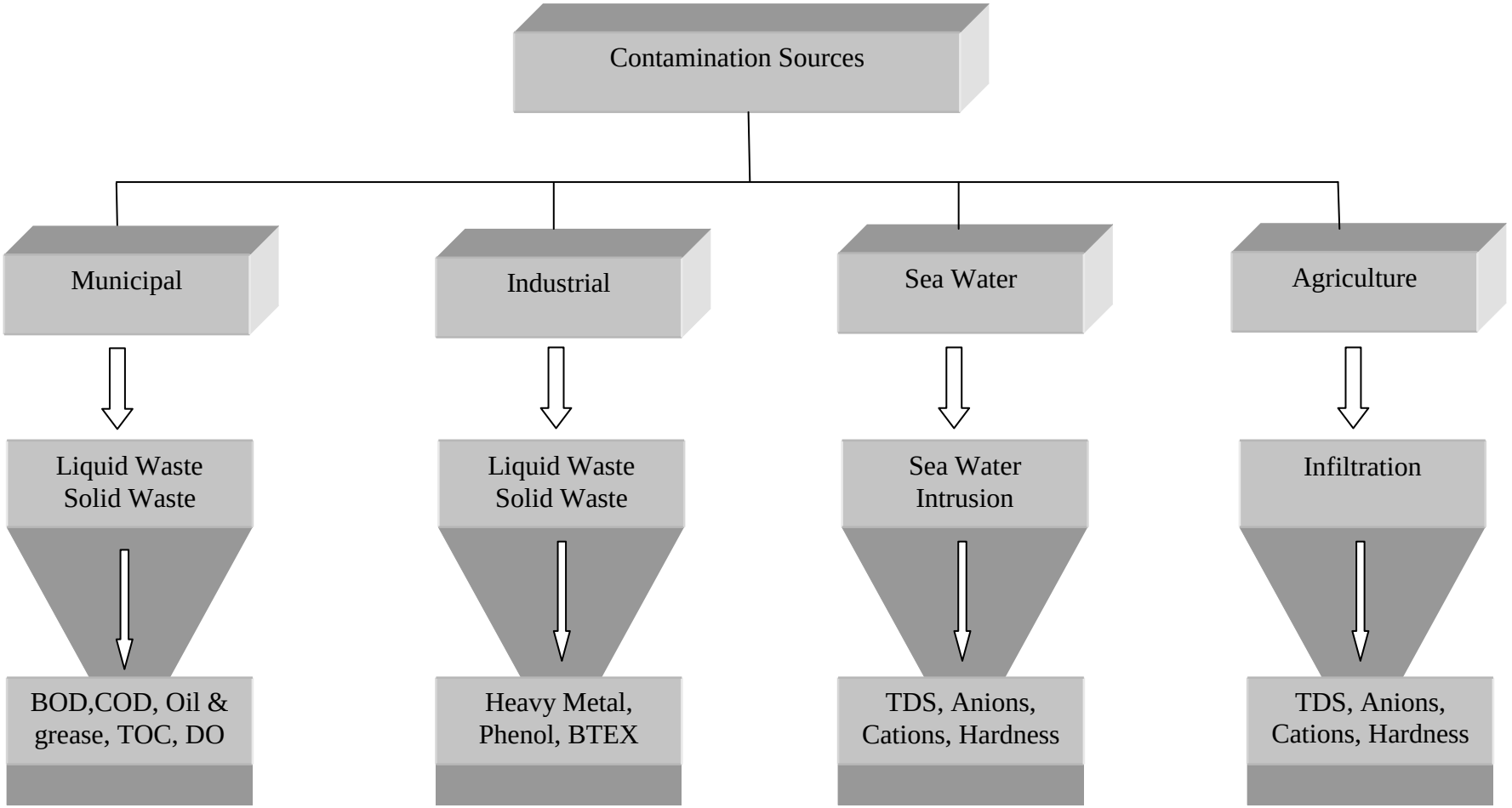


Figure 13: Flow Chart of contaminants and contamination sources

4.4 Risk Assessment

A risk assessment is simply a tool to examine of what, in our environment, could cause harm to people. Today there is no doubt that anthropogenic contamination by chemical elements or compounds has become the most serious and the most dangerous problem for the environment. It become the biggest source of both environmental as well as health risks in respect to biota and human beings alike. Highest content of elements or compounds in individual environments designate the acceptable degree of risk for a polluted environment. Several methods for evaluating environmental and health risk were developed in the last 20 years. The methods were developed either by international associations, e.g., SETAC (Society of Environmental Technology and Chemistry) or within the activities of national institutions and environmental agencies, e.g., US EPA (United States Environmental Protection Agency).

The system of monoelement maps is typically used to spatially show the distribution of those chemicals or compounds in environments. These maps can be created by computing the index of environmental risk for each analyzed element or compound exceeded the allowable concentration limit. This index is the ratio of analytical concentration of the element in the environment (AC_i) to the risk concentration (RC_i) or the maximum allowable limit (MCL_i) with no adverse effect on the system:

$$I_{ERi} = AC_i / RC_i \qquad (4.1)$$

Then, the sum of the individual IERi is calculated in order to have a comprehensive risk map for the study area.

As per the above, the procedure to perforce risk evaluation in this study included the followings:

1. Compute the risk index with reference to Environmental Protection Agency EPA regulations.
2. Calculate the environmental risk index (IER) for all elements.
3. Calculate the total effect of several elements which exceed the limit concentrations by computing the sum of the risks of individual elements.
4. Assume that threats to human health for each element will be determined with reference to the maximum contaminate level (MCL).

4.5 Site Investigation for Contamination Sources

The main types of contaminants resulting from various activities in Tarout Island are provided hereafter.

4.5.1 Contaminants from domestic activity

The main contaminant sources from domestic activities include leakage from sewage network system and treatment facilities as well as septic tanks. The main contaminants resulting from this activity are oxygen demanding, organic compound (i.e BOD). Oil and

grease (O&G), detergents, nitrogen compounds, and microbial organisms. Leakage from sewage system is expected due to the old age of the system and unavailability of sewage system in some areas. The sanitary drainage water processing station in the study area is shown in Figure 14.

4.5.2 Contaminants from agricultural activity

The agricultural activities (Figure 15) spread over the area. The intensive use of fertilizers and pesticides in addition to uncontrolled irrigation cause degradation in groundwater quality. Fertilizers contain high amounts of nitrate and phosphors compounds which are the most serious contaminants.

4.5.3 Contaminants from Industrial activity

The industrial activity is concentrated in the Turkia area in the north of Tarout Island with some workshops spread over Tarout Island. It is considered as point-pollution source. It releases a variety of contaminants which have a great association to the deterioration of the groundwater in the study area.

The contaminants include organic hydrocarbon, solvents, heavy metals and toxic substances resulting from chemical reactions among these contaminants. Contaminants sources are mainly due to discharge from industrial waste on the land surface, solid waste disposal, and oil waste disposal (Figure 16).

Figure 14: Sanitary water drainage station

Figure 15: Water in agricultural area.

Figure 16: Waste oil in the industrial area, 2007

CHAPTER 5

RESULTS AND DISCUSSION

The major contamination indicators in groundwater and the relation between those indicators and the contamination sources in Tarout Island is discussed in this chapter. The tabulated chemical analysis for all wells can be found in (Table 1, Appendix A). This was supported by the spatial distribution of contaminants or chemical of concern on the contour map using ArcGis software. The analyzed parameters were compared with the drinking water limits and regulation established by USEPA shown in Appendix B.

5.1 Assessment of Surface Water

Three (3) samples were collected from water accumulated in an open basin located in the industrial area and called Surface Water (SW). They were analyzed for heavy metal and hydrocarbon content in order to track the contribution of the industrial sources on the groundwater contamination. The quality of surface water is very important in assessing groundwater quality conditions due to the fact that some pollutants in surface water may leach to groundwater sources beneath. The results of analysis of surface water samples are discussed below.

5.1.1 Heavy Metal Levels

The analytical results of samples collected from surface water (Appendix A) indicated that samples are characterized by high concentrations of Ti, Be, Al, Cr, Fe, Cu, As, and Pb. The sources of many trace metals are associated with natural process such as chemical weathering and soil leaching (NAS, 1977), although many of them are due to man's activities. The contribution of man's activities to groundwater contamination in the study area is expected due to dumping a variety of solid wastes, liquids, paints, and oils products in the area. The bad practices also have a great contribution in groundwater contamination for instance some of the basins which were used as a dumping area were covered completely and they do not exist anymore but the solid wastes are still there and they act as permanent source of contamination. It is expected that same pollutants may reach groundwater through leaching so it very important to study the surface water condition in order to have a better assessment of the groundwater condition.

(a) Beryllium (Be)

Some people who drink water containing beryllium well in excess of the maximum contaminant level (MCL) for many years could develop intestinal lesions. Results show that the average of beryllium (Be) in surface water is 0.21 ppm and the MCL for Be in drinking water is 0.004 ppm as per USEPA standards. The contamination was detected in the industrial area in samples 2, and 3. The Be level was 0.25 and 0.37 ppm respectively (Figure 17). The source of beryllium is mainly associated with natural processes, although it might be also due to man's activities.

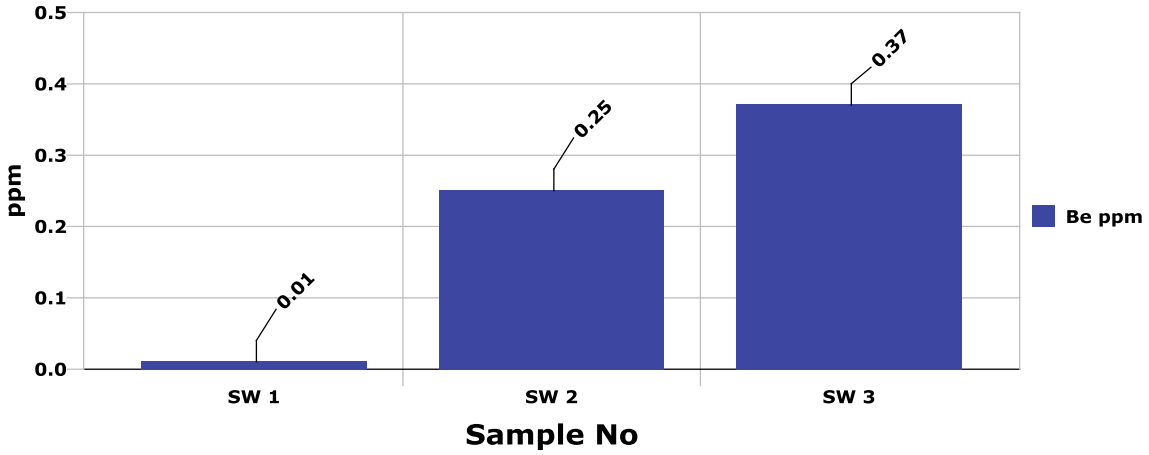


Figure 17: Beryllium concentrations (ppm) in surface water samples

(b) Aluminum (Al)

Large aluminum intake may negatively influence health. This was connected with nerve damage (EPA, 2004). People, particularly those with kidney damage are susceptible to aluminum toxicity. There is a risk of allergies. Aluminum is probably mutagenic and carcinogenic. A correlation between aluminum uptake and an increased number of Alzheimer cases is suspected. However, this is uncertain because aluminum concentrations always increase with age. Increased aluminum intake may also cause osteomalacia (EPA, 2004) which is the softening of the bones due to defective bone mineralization.

Aluminum (Al) content in the surface water was detected in all samples. It was 0.05 ppm, 0.31 ppm and 0.09 ppm respectively (Figure 18). This is higher than the MCL recommended by EPA for drinking water of 0.05 ppm. The higher concentrations of Al are detected in the industrial area.

(c) Iron (Fe)

The recommended maximum concentration for drinking water as per EPA regulations for drinking water is 0.3 ppm. The concentration of Fe in the surface water samples varies between 0.6 to 1.2 ppm (Figure 19). The main reason for the high content of iron is probably due to the corrosion of steel waste in the open basin. When high concentrations of iron are absorbed, for example by haemochromatose patients, iron is stored in the pancreas, the liver, the spleen and the heart. This may damage these vital organs (EPA,

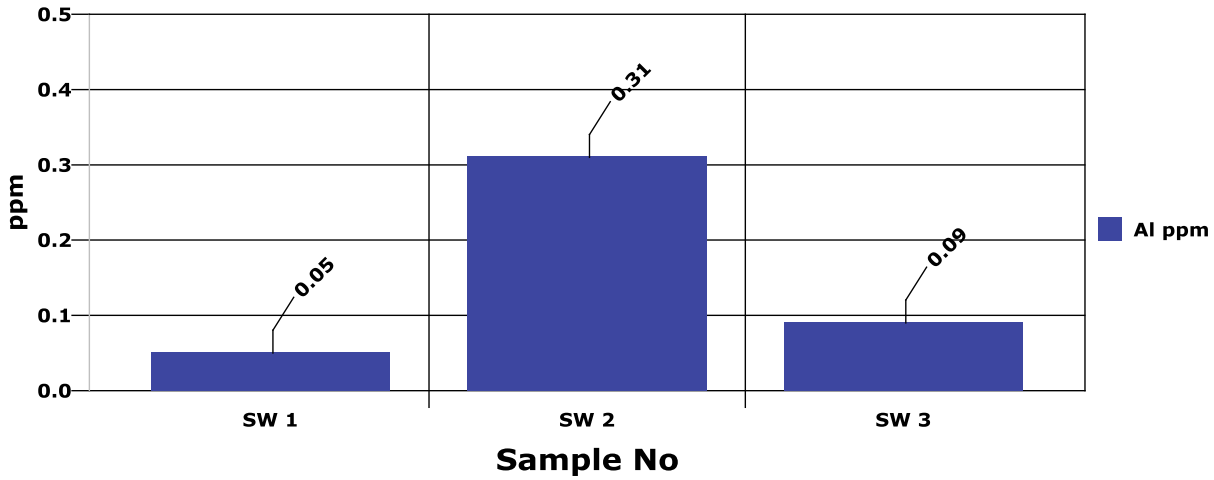


Figure 18: Aluminum concentration (ppm) in surface water samples

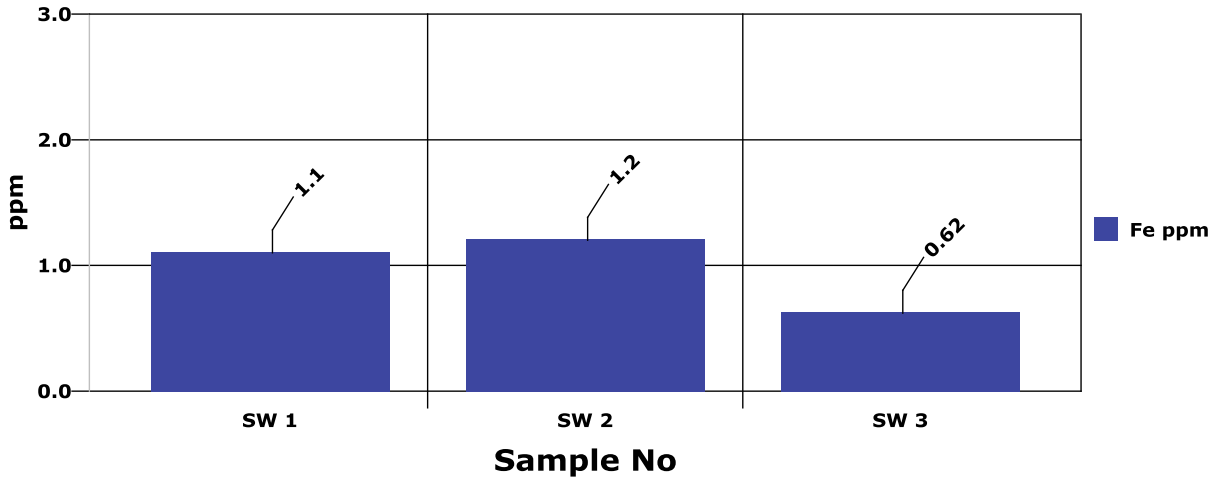


Figure 19: Iron concentrations (ppm) in surface water samples

2004). Healthy people are generally not affected by iron overdose, which is also generally rare. It may occur when one drinks water with iron concentrations over 200 ppm (EPA,2004). Iron compounds may have a more serious effect upon health than the relatively harmless element itself. Water soluble binary iron compounds such as $FeCl_2$ and $FeSO_4$ may cause toxic effects upon concentrations exceeding 200 mg, and are lethal for adults upon doses of 10-50 g. A number of iron chelates may be toxic, and the nerve toxin iron penta carbonyl is known for its strong toxic mechanism. Iron dust may cause lung disease (EPA, 2004).

(d) Chromium (Cr)

The average concentration of chromium (Cr) in surface water samples was 0.49 ppm which is much higher than the MCL for drinking water, 0.1 ppm. The infiltration and leachate from industrial waste can be considered as one of the chromium sources in surface water. Cr in surface water reached 0.84 ppm in sample 2 (Figure 20). Chromium (III) toxicity is unlikely, at least when it is taken up through food and drinking water. It may even improve health, and cure neuropathy and encephalopathy. Hexavalent chromium causes allergic and asthmatic reactions, is carcinogenic and is 1000 times as toxic as trivalent chromium. Health effects related to hexavalent chromium exposure include diarrhea, stomach and intestinal bleedings, cramps, and liver and kidney damage. Hexavalent chromium is mutagenic. Toxic effects may be passed on to children through the placenta (EPA,2004).

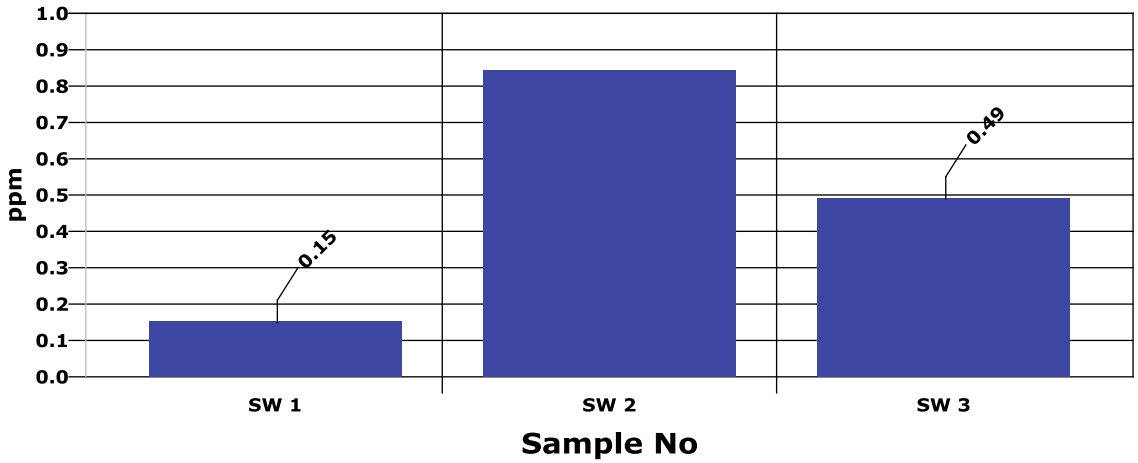


Figure 20: Chromium concentrations (ppm) in surface water samples

(e) Copper (Cu)

The copper concentration in open basin water ranges from 0.85 to 1.47 ppm with an average value of 1.49 ppm (Figure 21). The concentration of copper in drinking water should not exceed 1.3 ppm (EPA,2004). This means that the shallow water is slightly contaminated by copper. The reason behind the water contamination with copper is the various industrial wastes. Short term exposure may cause gastrointestinal distress and long term exposure may causes liver or kidney damage. High levels of copper can be harmful. Breathing high levels of copper can cause irritation of a person's nose and throat. Ingesting high levels of copper can cause nausea, vomiting, and diarrhea. Very-high doses of copper can cause damage to your liver and kidneys, and can even cause death (ATSDR, 2004).

(f) Lead (Pb^{2+})

Another important contamination indicator for industrial sources is lead (Pb^{2+}). The concentration of lead in samples collected from surface water ranges between 0.04 to 0.09 ppm (Figure 22) while the recommended maximum limit for lead in drinking water as per the EPA is 0.015 ppm. The presence of lead may be attributed to the industrial wastes. Excessive levels of lead can damage the brain, kidneys, nervous system, red blood cells and reproductive system (ATSDR, 2004).

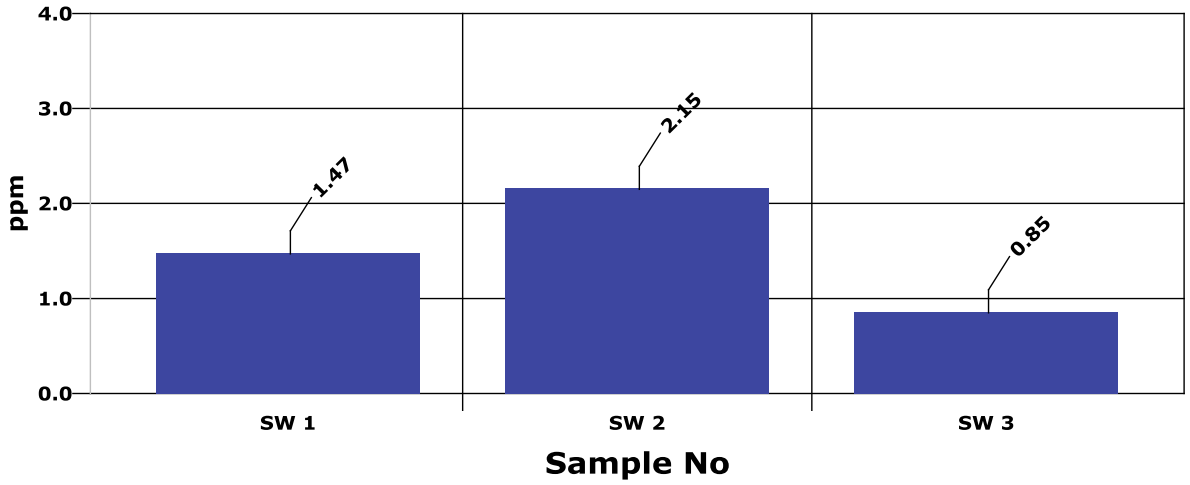


Figure 21: Copper concentrations (ppm) in Surface water samples

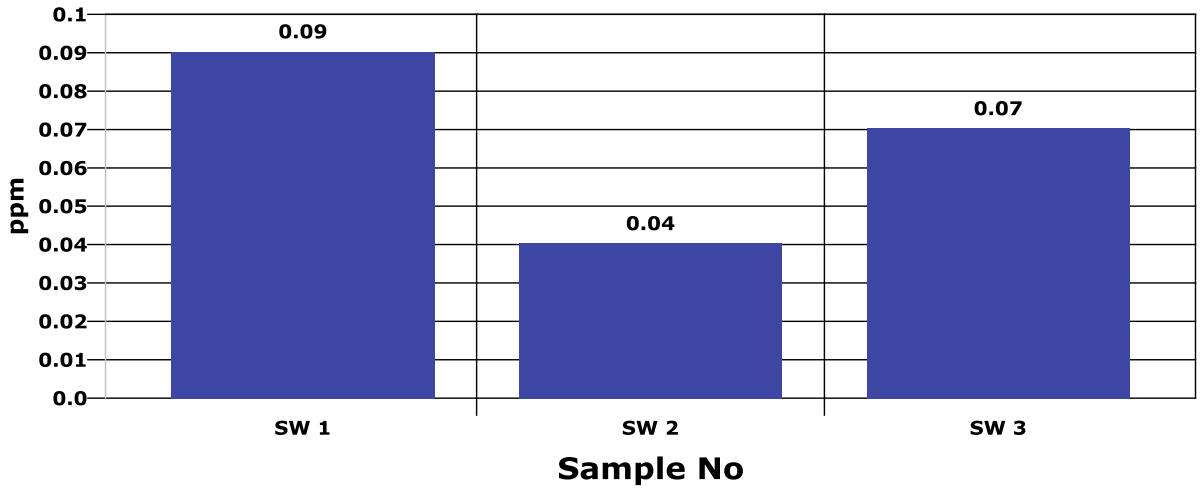


Figure 22: Lead concentrations (ppm) in surface water samples

(g) Arsenic (As)

The average concentration of As was found higher than the allowable limit by 50%. The MCL value is 0.02 ppm by EPA. The highest value of 0.03 ppm was determined in sample 2 (Figure 23). The possible sources of arsenic in surface water is infiltration or runoff from locations of industrial waste areas. Arsenic related illness is usually caused by consumption of contaminated drinking water. In the old days it was applied as a poison, because symptoms of arsenic poisoning resemble cholera symptoms, and therefore the intentional factor was shaded. Arsenic related health effects are usually not acute, but mostly encompass cancer, mainly skin cancer. Arsenic may cause also low birth weight (ATSDR, 2004).

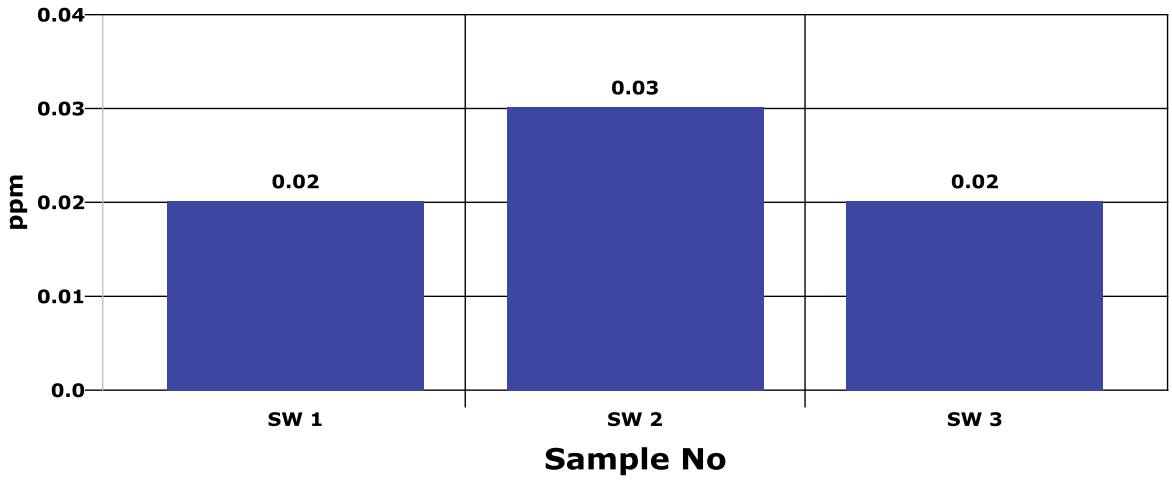


Figure 23: Arsenic concentration (ppm) in surface water samples

5.1.2 Hydrocarbon Levels

Samples collected from surface water in the industrial area show a high content of hydrocarbon (Figure 24). The existence of hydrocarbon in surface water may be attributed to the industrial waste specially petroleum products. The analytical results are shown in Table A.2 in Appendix A.

Though phenol is not regulated by EPA and no specific recommended limit is specified, the value is considered as high when we compare it with other hydrocarbon limits. The phenol ranges from 0.87 to 1.5 ppm. and the highest was observed in sample 1. Phenol exerts a marked corrosive action on any tissue of contact when ingested, inhaled or after skin exposure. Its cellular uptake is both rapid and passive due to its lipophilic character, and signs of systemic toxicity develop soon after exposure. Phenol's main target organs are the liver and kidney. It may also effect the respiratory and cardiovascular systems (EPA, 2004).

Toluene is another important contamination indicator to show the affect of industrial activities on the environment. The maximum permissible limit for toluene in drinking water as per the recommendation by EPA is 1 ppm. In this study, results show that the toluene content ranges from 0.79 to 1.9 ppm in surface water. A serious health concern is that toluene may have an effect on the brain. Toluene can cause headaches, confusion, and memory loss. Whether or not toluene does this to you depends on the amount you take in and how long you are exposed. Low to moderate, day-after-day exposure in your

workplace can cause tiredness, confusion, weakness, drunken-type actions, memory loss, nausea, and loss of appetite. These symptoms usually disappear when exposure is stopped (EPA, 2004).

Benzene values in surface water ranges between 0.14 ppm in sample 1 and 1.47 ppm in sample 2 while the MCL value is 0.005 ppm. Benzene exposure has serious health effects (EPA, 2004). Outdoor air may contain low levels of benzene from tobacco smoke, wood smoke, automobile service stations, the transfer of gasoline, exhaust from motor vehicles, and industrial emissions. Vapors from products that contain benzene, such as glues, paints, furniture wax, and detergents, can also be a source of exposure, although many of these have been modified or reformulated since the late 1970s to eliminate or reduce the benzene content. Air around hazardous waste sites or gas stations may contain higher levels of benzene. The short term breathing of high levels of benzene can result in death, while low levels can cause drowsiness, dizziness, rapid heart rate, headaches, tremors, confusion, and unconsciousness. Eating or drinking foods containing high levels of benzene can cause vomiting, irritation of the stomach, dizziness, sleepiness, convulsions, and death. The major effects of benzene are manifested via chronic (long-term) exposure through the blood. Benzene damages the bone marrow and can cause a decrease in red blood cells, leading to anemia. It can also cause excessive bleeding and depress the immune system, increasing the chance of infection. Benzene causes leukemia and is associated with other blood cancers and pre-cancers of the blood. Human exposure to benzene is a global health problem. Benzene targets liver, kidney, lung, heart and the brain and can cause DNA strand breaks, chromosomal damage etc. Benzene causes cancer in both animals and humans (EPA, 2004).

Ethyl benzene was detected in all surface water samples. It ranges between 0.45 and 2.1 ppm which is higher than the MCL value of 0.07 ppm by EPA. At certain levels, exposure to ethyl benzene can harm human beings' health. People exposed to low levels of ethyl benzene in the air for short periods of time have complained of eye and throat irritation. Persons exposed to higher levels have shown signs of more severe effects such as decreased movement and dizziness. Short-term exposure of laboratory animals to high concentrations of ethyl benzene in air may cause liver and kidney damage, nervous system changes, and blood changes.

As in the case of other hydrocarbons, surface water in Tarout Island is contaminated with styrene. The chemical was detected at concentrations of 1.78 ppm in sampling point adjacent to industrial dumping area. The MCL of styrene in drinking water is 0.1 ppm. Effects of styrene on human health and the environment depend on how much styrene are present and the length and frequency of exposure. Effects also depend on the health of a person or the condition of the environment when exposure occurs. Styrene vapor irritates the eyes, the nose, and the throat. Styrene vapor can also adversely affect the human nervous system, causing adverse eye effects. These effects are not likely to occur at levels of styrene that are normally found in the environment (EPA, 2004).

Although MTBE detections are related to factors such as population density and primary land use, the occurrence of MTBE in surface and ground water is most strongly related to its use in gasoline. MTBE values in surface water ranges between 0.08 ppm in sample 3 and 1.5 ppm in sample 2. The health impacts of MTBE exposure are not completely understood as no long-term study on the effects of MTBE on humans has been conducted

(EPA, 2004). However, studies on the carcinogenicity of MTBE on rodents have shown kidney cancers, liver cancers and testicular cancer in male rodents and lymphatic cancers in females. The impact of MTBE on taste and odor in drinking water is significant, although human responses vary depending on taste sensitivity.

In 1997, the US EPA Office of Water released "Drinking Water Advisory: Consumer Acceptability Advice and Health Effects Analysis on MTBE" which summarizes health impact study results on the health effects of MTBE. It does not impose any regulatory requirements on providers of public drinking water and instead provides recommendations for contaminant levels that would be acceptable to most consumers of public drinking water supplies. It states that thresholds of 20 to 40 ppb or below avert unpleasant taste and odor effects. MTBE is listed as a "hazardous substance" under Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) and is considered a "potential human carcinogen" in high doses under the US EPA Office of Water (EPA, 2004).

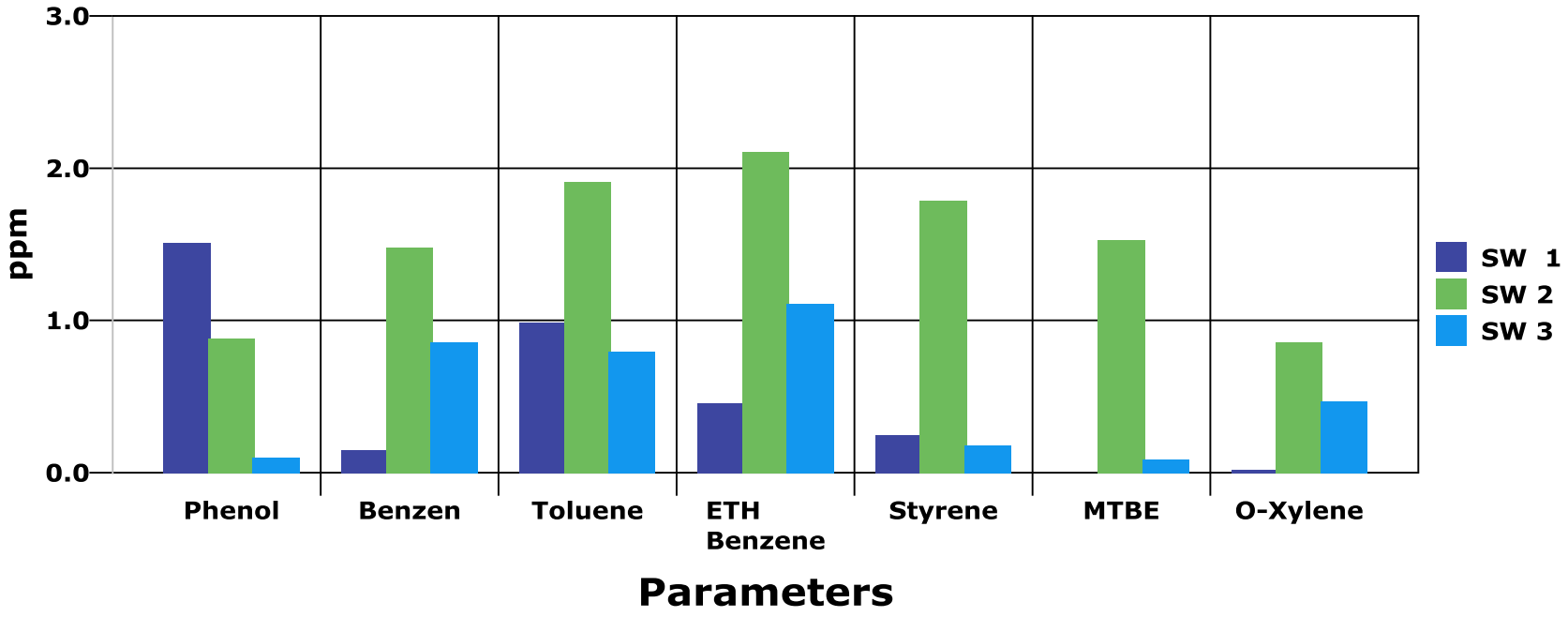


Figure 24: Hydrocarbons compounds concentration (ppm) in Surface water samples

5.2 Assessment of Shallow Groundwater

Eleven groundwater samples were collected from shallow groundwater from different points and different depth (3-5m) along the study area. The purpose of analyzing water from shallow layers is to follow the path of the contaminants and predict the possibilities of deep groundwater contamination. They were mainly analyzed for heavy metal and hydrocarbon in order to track the contribution of the industrial sources to the groundwater contamination. In the following sections, the sources of contamination and their affects on the quality of shallow water will be discussed.

The intensive use of fertilizers, improper well construction and the uncontrolled irrigation cause degradation of groundwater quality. Nitrates are one of the greatest contaminant indicators for contamination from agricultural activities. Nitrates are available with high amounts in fertilizers and wastewater. In addition, nitrite and phosphate are also considered as a contamination indicator from agricultural activities. The anions and cations analysis of samples collected from shallow groundwater is shown in Table A.3 in Appendix A.

5.2.1 Nitrate and Nitrite

The analysis of shallow ground water indicates the presence of nitrate in 90% of the samples (Table A.3 in appendix A). Of the 11 samples, nine (9) samples have nitrate concentrations greater than the MCL value of 10 ppm. The shallow ground water analysis

indicates that the surface water is highly rich with nitrate. The highest content of nitrate was detected in sample 2 which is about 5322 ppm. Levels of nitrate were generally higher in the residential than the industrial areas (Figure 25).

The high content of nitrate in shallow water can be attributed to two factors. one of the factors is the leaching from septic tanks and leakage from sewer system. The other factor is the seepage of drainage water from farm lands where the application of fertilizers for agriculture is common.

Results show that nine samples of shallow ground water are contaminated with nitrites (Figure 26). The highest nitrite concentrations were 201 ppm, 187 ppm, and 31.58 ppm in samples SGW 10, SGW 11, and SGW 9, respectively. The MCL value is 1 ppm. The high concentrations of nitrate and nitrite in shallow groundwater may be due to the runoff from agriculture activities and leakage from the waste water treatment station (Figure 14). The contour map shows that most of the shallow ground water in the study area was affected by nitrite with two major hot spots in the central areas. This may be attributed to the intensive use of fertilizers for long time and also to the old sewage system. The health effects of nitrates and nitrites have been discussed in the previous sections.

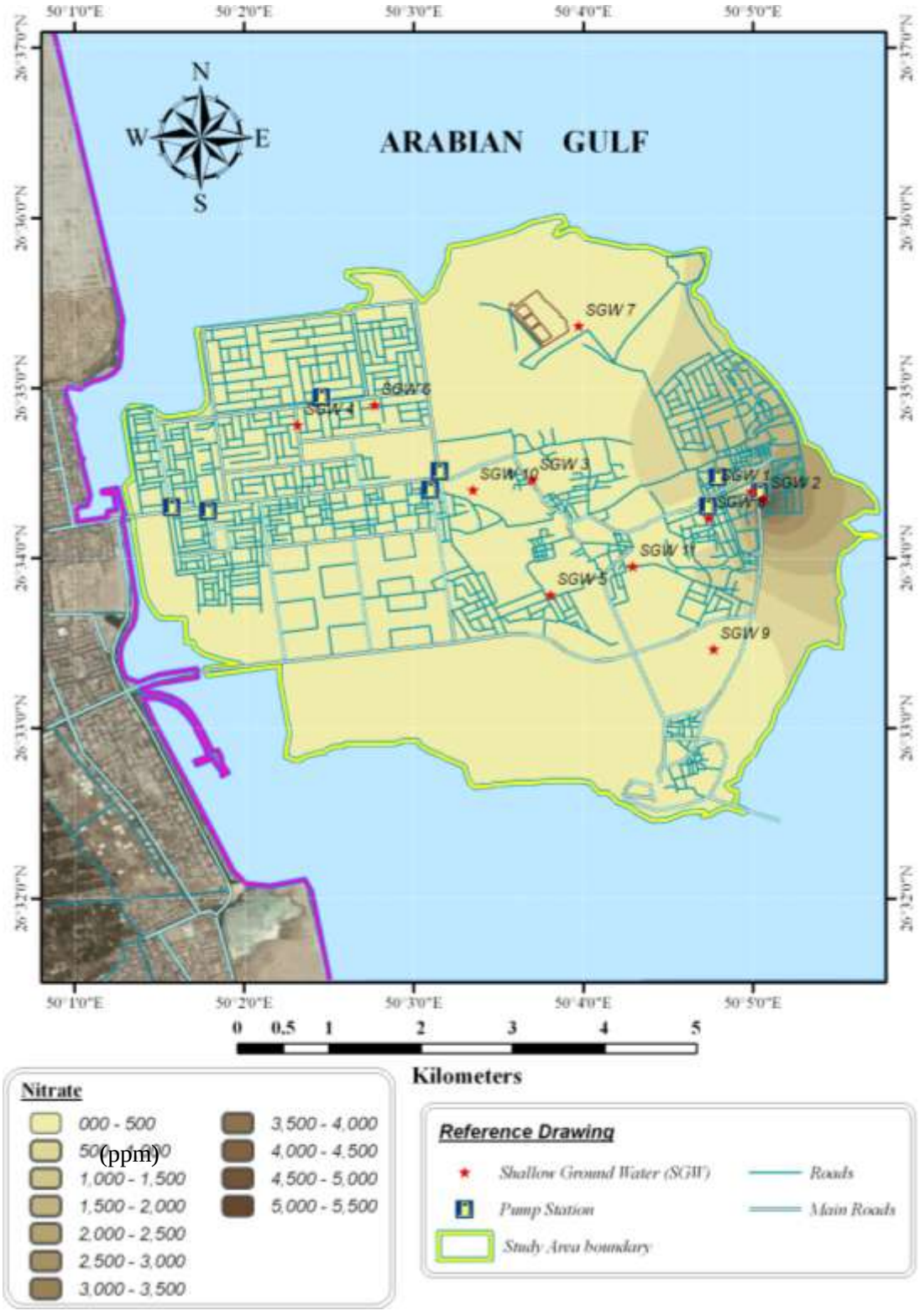


Figure 25: Nitrate concentrations (ppm) distribution in shallow groundwater samples

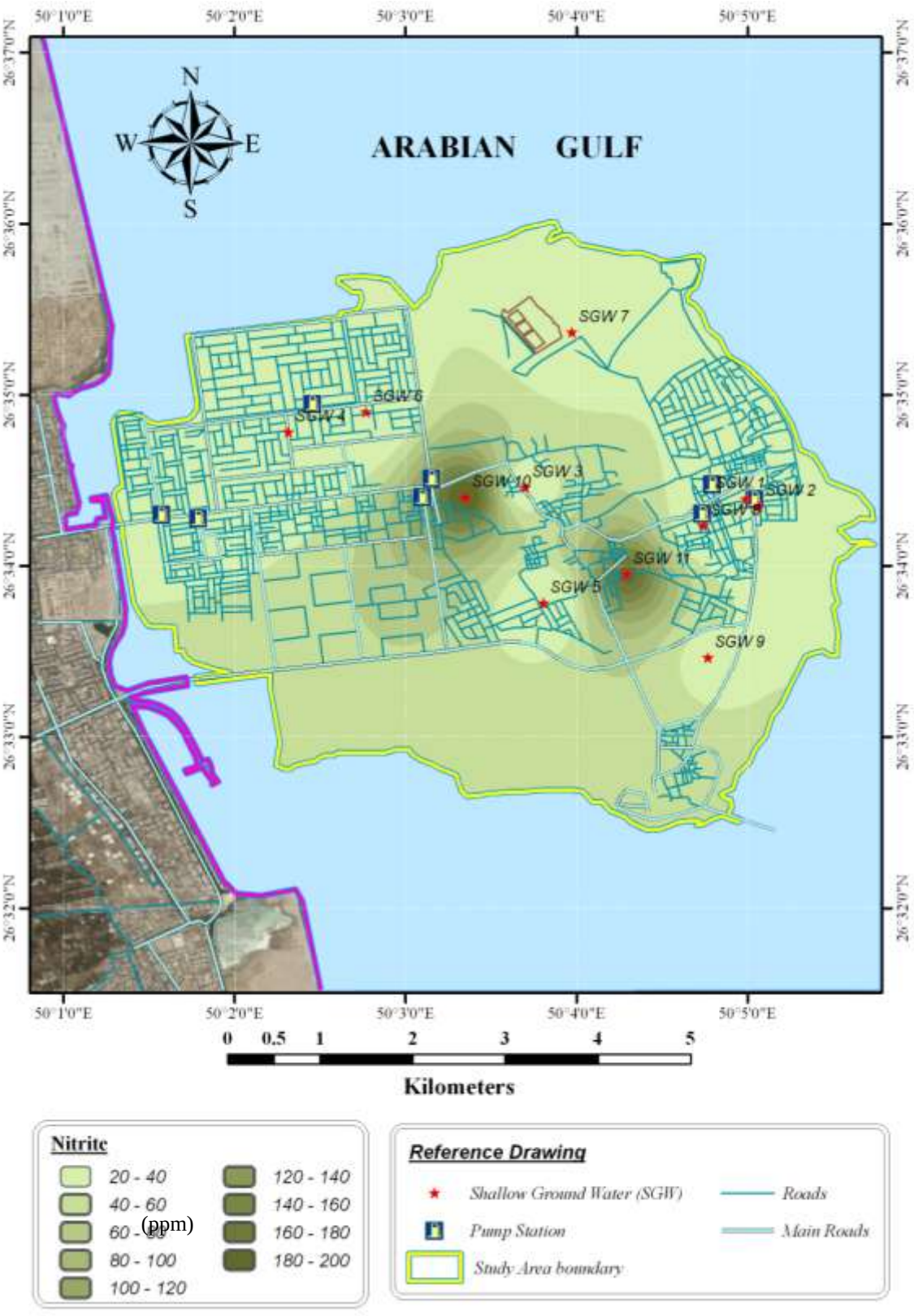


Figure 26: Nitrite concentrations (ppm) distribution in shallow groundwater samples

5.2.2 Phosphate

The shallow ground water analysis show very high content of phosphate (Figure 27). Elevated levels of phosphate in shallow water can be attributed to the seepage from the sewage system and application of fertilizers. The two highest phosphate concentrations are 6030 ppm and 5329 ppm in samples SGW 4 and SGW 11 respectively. Sample SGW 4 is located in Turkia in the west-north part of Tarout Island. This high value may be attributed to the leakage from septic tanks since this area has not been covered by a sewage system for more than 20 years. However, sample SGW 11 is located in the agricultural area which also explains the reason for the high content of phosphate. It might be attributed to the irrigation return water.

5.2.3 Bromide

Bromide content in groundwater in the study area ranges from 1.81 ppm to 29.57 ppm (Table A.4 in appendix A). The high content of bromide in shallow ground water was found in sample SGW 5. There was no limit value for bromide in EPA regulation and standards, but EPA has mentioned that the bromate (BrO_3) in groundwater should not exceed 0.01 ppm (USEPA, 2004).

As per the study conducted by water authority in Riyadh (Alyaum, 2007) bromate contains about 63% of bromide. This means that the availability of 6.3 ppb of bromide in water will lead to the production of bromate with a concentration higher than the allowable limit of bromate after the ozonation process.

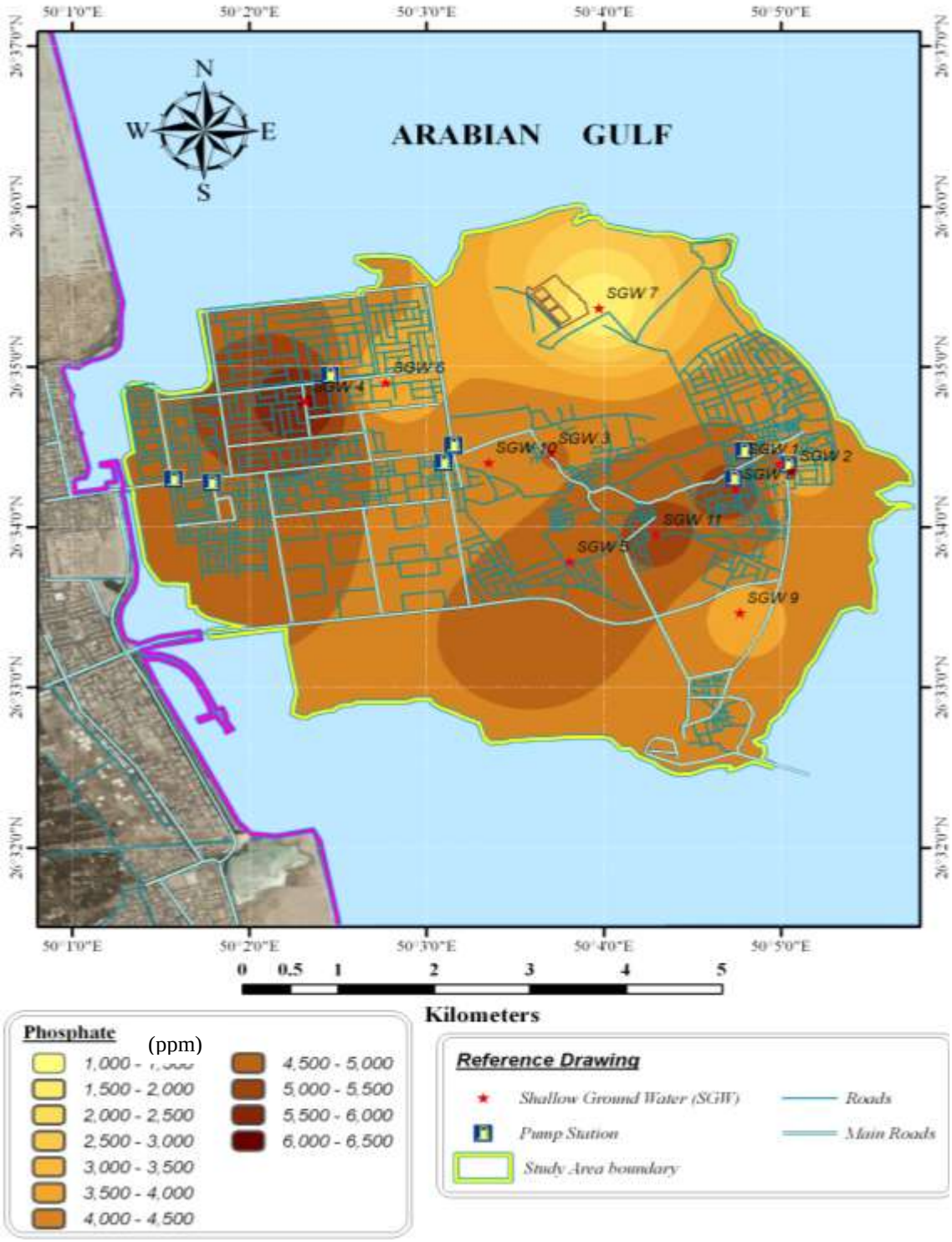


Figure 27: Phosphate concentrations (ppm) distribution in shallow groundwater

Water intake with bromide higher than 0.01 ppm increases risks of cancer. The ozonation of groundwater containing bromide ion leads to the production of inorganic bromat (Huang W, et,al., 2003).

Now it is very essential to know how much of bromide is required to produce bromate higher than 0.01 ppm which is the maximum allowable limit. The distribution of bromide over Tarout Island is shown in Figure 28. Results show that bromide ion is high in the western and southern areas (Industrial and residential areas).

Bromide is present in synthetic organic dyes, mixed petrochemical waste and inorganic waste. Other forms of bromide such as bromate occur naturally in soils at smaller concentrations (David et.al., 2000).

Most bromide salts are soluble and readily leachable into water percolating through the soil and down to groundwater. (U.S. EPA 1983). The presence of bromide in groundwater in the study area may be attributed to the second source (Natural source).

5.2.4 Iron

The recommended maximum concentration for iron as per EPA in drinking water is 0.3 ppm. The iron level in water samples WS2, WS6 and WS11 exceed the recommended level (Table A.4 in appendix A). The iron content in those samples were 0.308 ppm, 0.358 ppm and 0.58 ppm respectively.

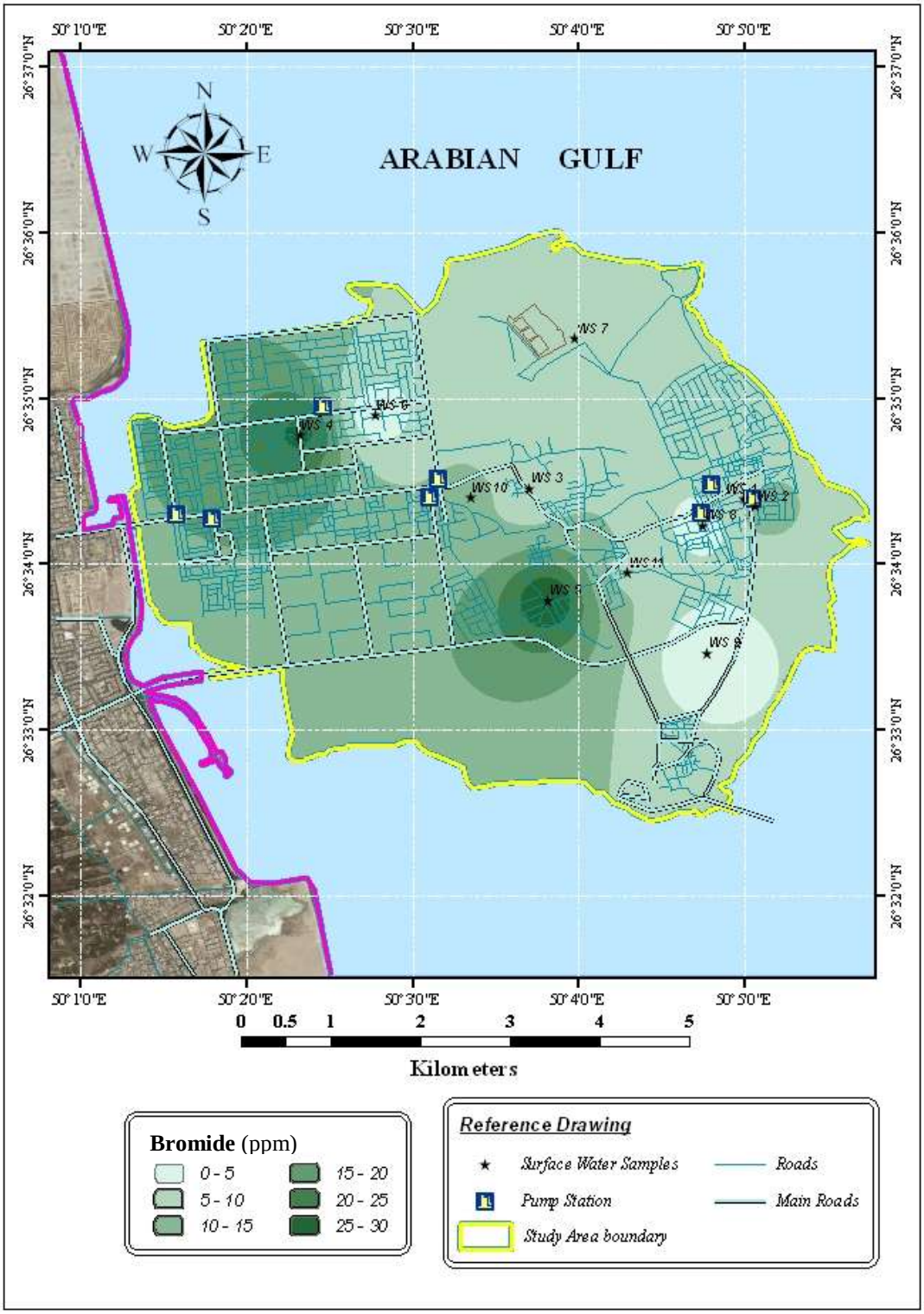


Figure 28: Bromide concentrations (ppm) distribution in shallow groundwater samples

Though the rest of samples are below the standard level, the average content of iron is 0.20 ppm which is close to the recommended level of iron.

According to the standard limits of iron content all samples above the 0.3 ppm are polluted by iron, especially sample SGW 11 , which is allocated in the agricultural area and samples SGW 6, which is collected from the industrial area. This may be attributed to the corrosion of well casing and other pipe network. Iron may also be present in groundwater due to the geological setting of the study area and the other chemical components of the water source (U.S. EPA, 1976). Enrichment of water with iron can be considered as an indication for the presence of groundwater contamination by organic substance (Matthess, 1982). The spatial variation of iron over the study area is shown in Figure 29.

5.2.5 Beryllium (Be)

The recommended level of Be in drinking water as per EPA should not be more than 0.004 ppm. The average of beryllium (Be) in the samples collected from shallow ground water in the study area was 0.01 ppm. The contamination was detected in the industrial area in sample SGW 4, 5, and 6. The variation of Be over the study area is shown in Figure 30.

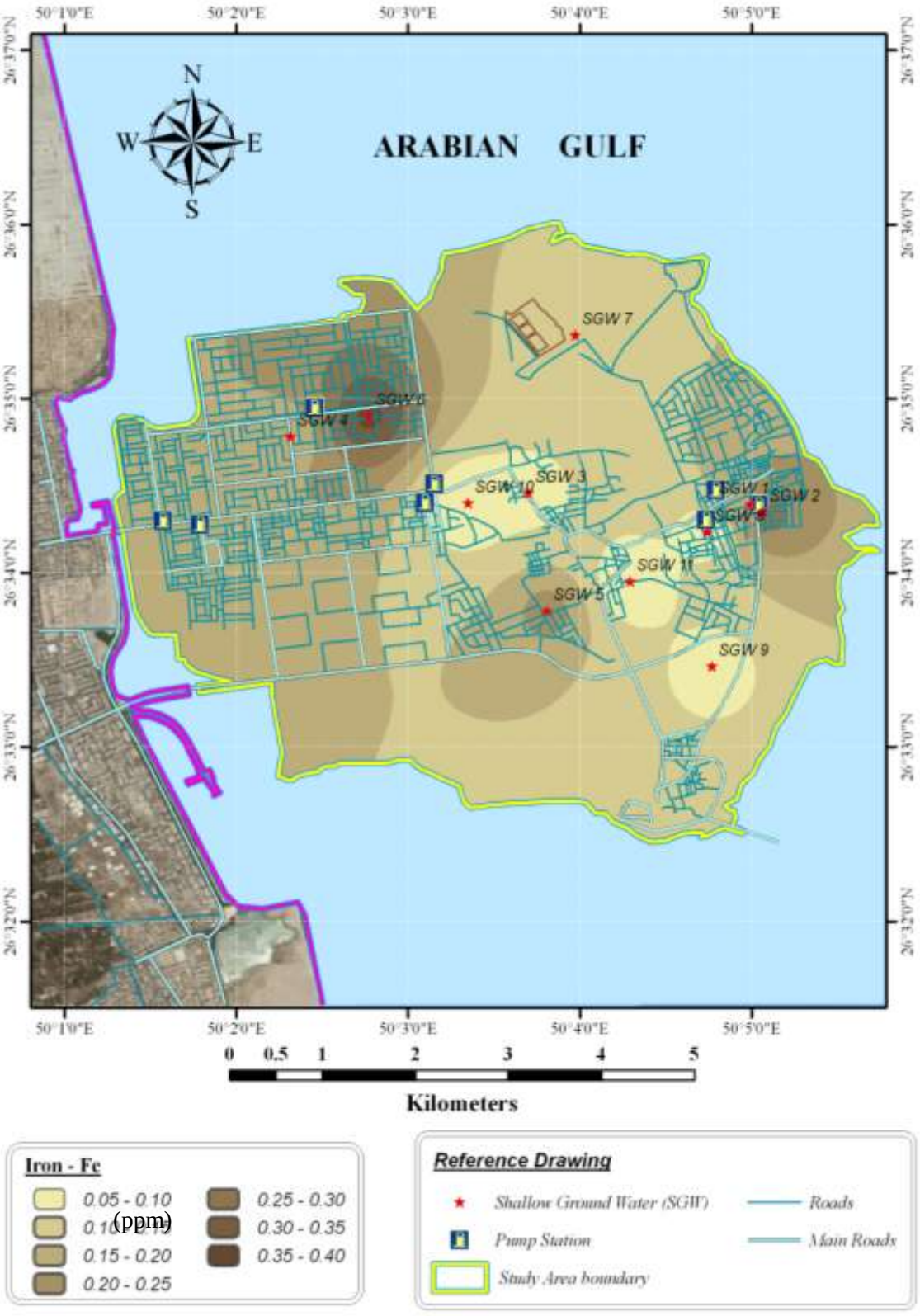


Figure 29: Iron concentrations (ppm) distribution in shallow groundwater samples

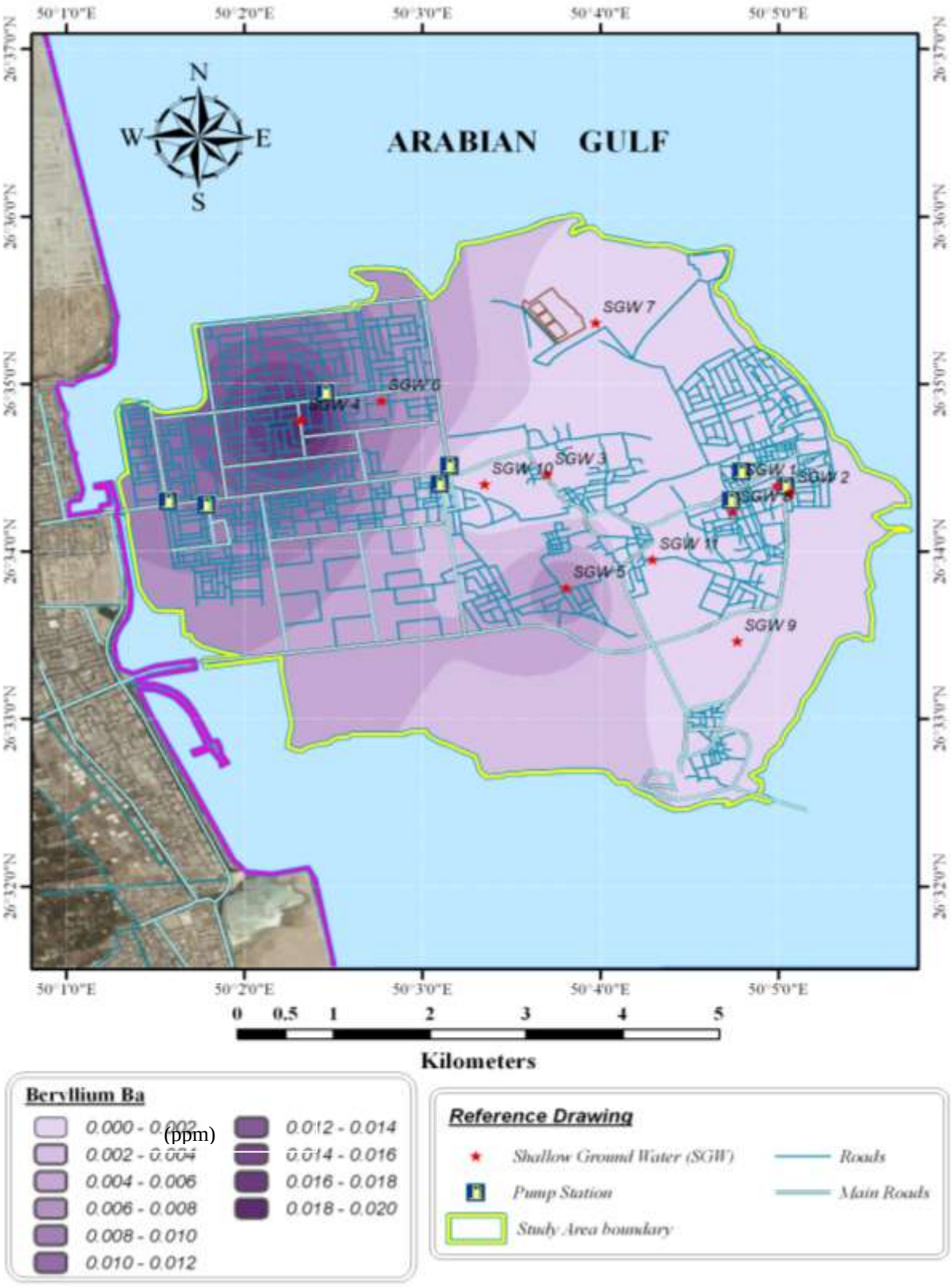


Figure 30: Beryllium concentrations (ppm) distribution in shallow groundwater samples

5.2.6 Aluminum (Al)

Aluminum (Al) content was not detected in most of the samples collected from shallow groundwater except samples SGW 4 and 6. It was 8 ppm and 6 ppm respectively. This is much higher than the MCL recommended by EPA for drinking water. The expected sources of contamination of shallow water with Al may be attributed to the leachate from the surface water which is having high content of Al. The recommended MCL for Al is 0.05 to 0.2 ppm. The distribution of Al is shown in Figure 31.

5.2.7 Manganese (Mn)

The average concentration of manganese (Mn) in shallow ground water was 0.37 ppm which is much higher than the MCL. The Mn content should not exceed the 0.05 ppm as per the EPA standards, but in shallow water it reached to 2.5 ppm in SGW 5 and very close to the MCL in samples 1,and 8. The data is graphically shown in Figure 32. The high concentration of manganese in some of the shallow water sample is attributed to the use of fertilizers in the old city.

5.2.8 Copper (Cu)

One of the important observations about the heavy metal results is the copper content. In the shallow ground water analysis the copper concentration lies between 1 to 2 ppm with an average value of 1.5 ppm. The recommended concentration of copper in groundwater should not exceeded 1.3 ppm. This means that the shallow water is slightly contaminated

with copper. The reason behind the groundwater contamination with copper is the various industrial wastes from factories. The spatial distribution of Cu is shown in Figure 33.

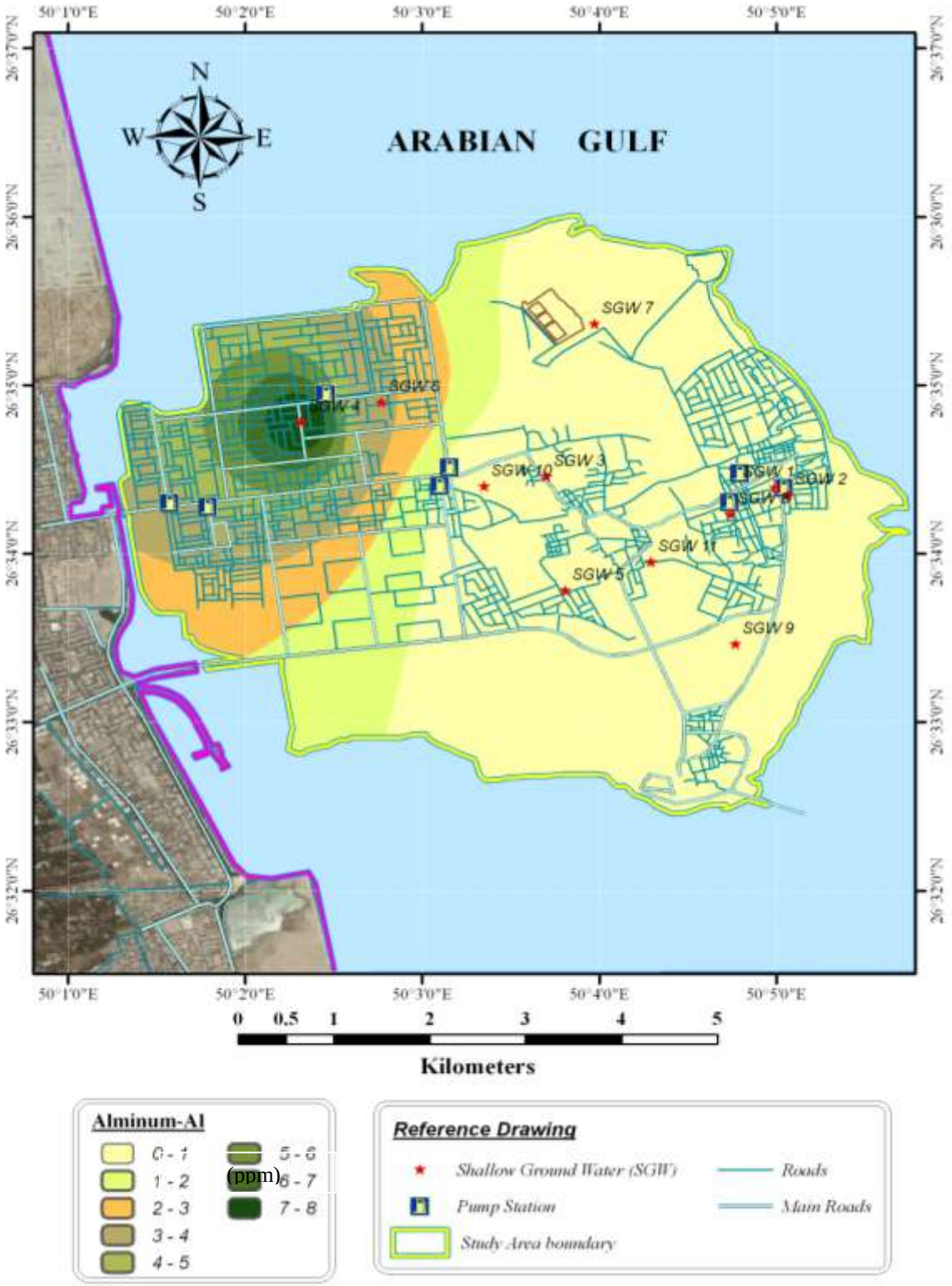


Figure 31: Aluminum concentrations (ppm) distribution in shallow groundwater samples

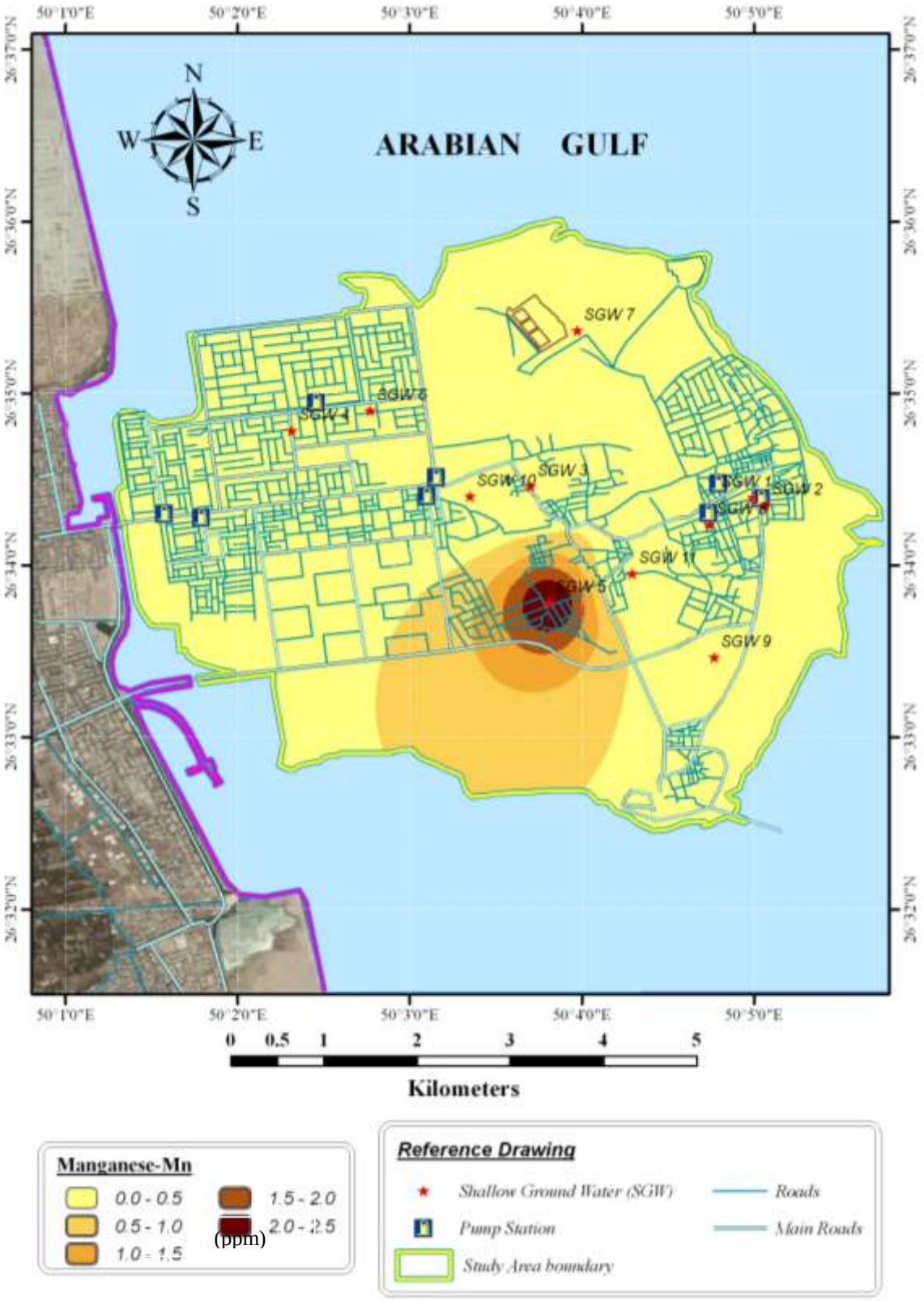


Figure 32: Manganese concentrations (ppm) distribution in shallow groundwater samples

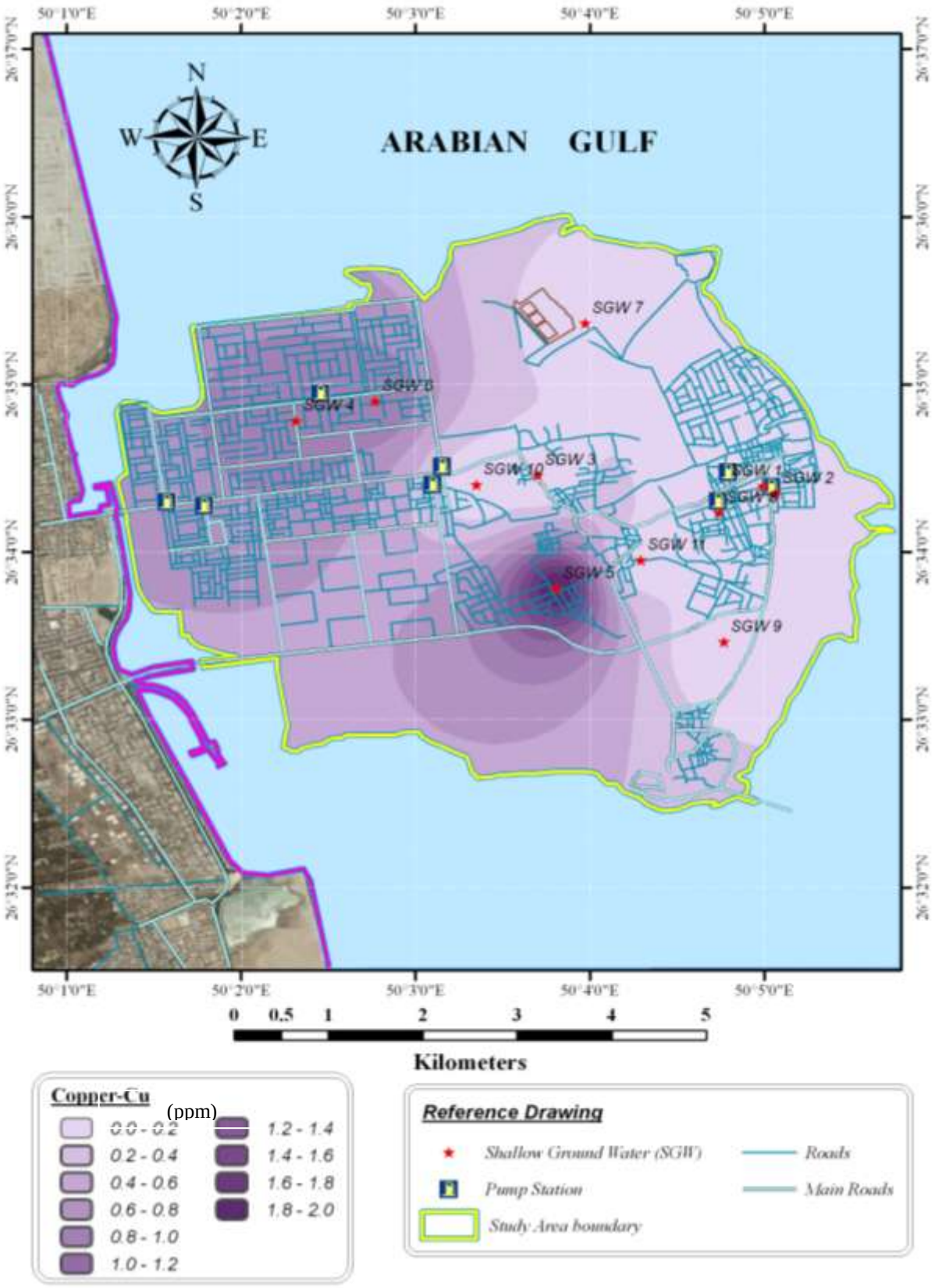


Figure 33: Copper concentrations (ppm) distribution in shallow groundwater samples

5.2.9 Hydrocarbons levels in shallow groundwater

Analysis results for samples collected from shallow groundwater in the industrial area show high content of some hydrocarbon in water analysis (Table 5.A in Appendix A). The analysis indicates the presence of BTEX (benzene, toluene, ethyl benzene), styrene, and MTBE.

Benzene concentrations range from 0.9 ppm in sample 5 to 2.7 ppm in sample 8 the MCL value is 0.005 ppm. The distribution of benzene over the whole area is shown in Figure 34.

Toluene is another important contamination indicator to show the effect of industrial activities on the environment. The maximum permissible limit for toluene in groundwater recommended by EPA is 1 ppm. This study determines the fact that toluene content is in the range from 0.6 ppm to 1.9 ppm in the samples collected from shallow ground water (Figure 35).

Ethyl benzene (ETHB) was detected only in one sample out of 11 samples. The ETHB was determined as 1.8 ppm in sample 5 which is higher than the maximum allowable limit recommended by EPA which is 0.7 ppm. The distribution of ETHB over the whole area is shown in Figure 36.

As in the case of other hydrocarbon, shallow groundwater also indicates the presence of styrene contamination. The average value of styrene is 1.7 ppm and the MCL is 0.1 ppm. The maximum value was 2.1 ppm, and it was detected in sample 5 (Figure 37).

MTBE was detected in 3 samples. It ranges from 01.7 ppm in sample 2 to 2.5 ppm in sample 5 with an average value of 2 ppm. The distribution of MTBE over the industrial area is shown in Figure 38.

The contamination of shallow groundwater in some locations may be attributed to the leachate from the underground gasoline tanks in petrol stations and also due to some bad practice in getting rid of the oils and hydrocarbon used in the industrial workshops. The health effects of hydrocarbons and their impacts on groundwater quality were discussed in surface water assessment.

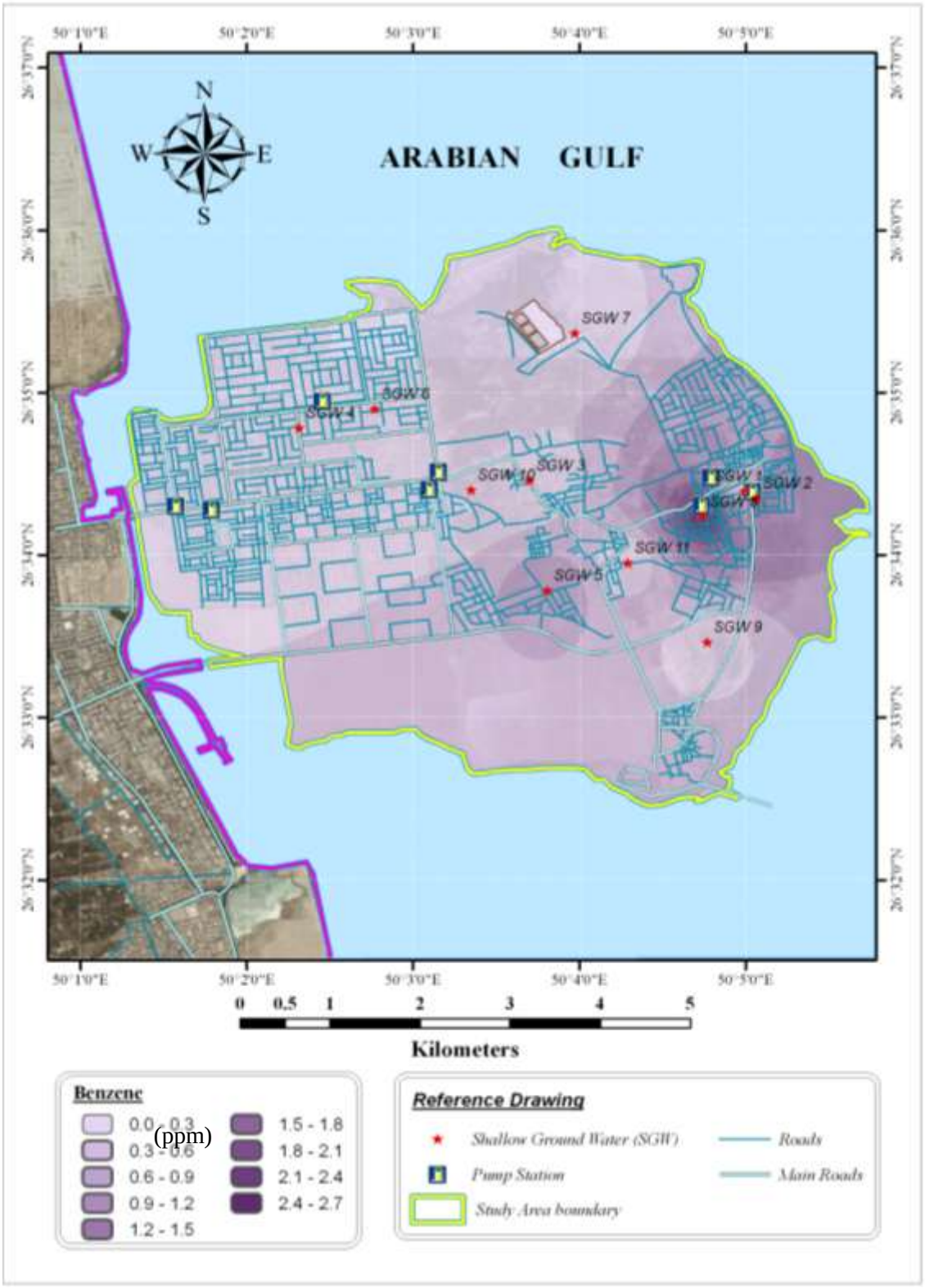


Figure 34: Benzene concentrations (ppm) distribution in shallow groundwater samples

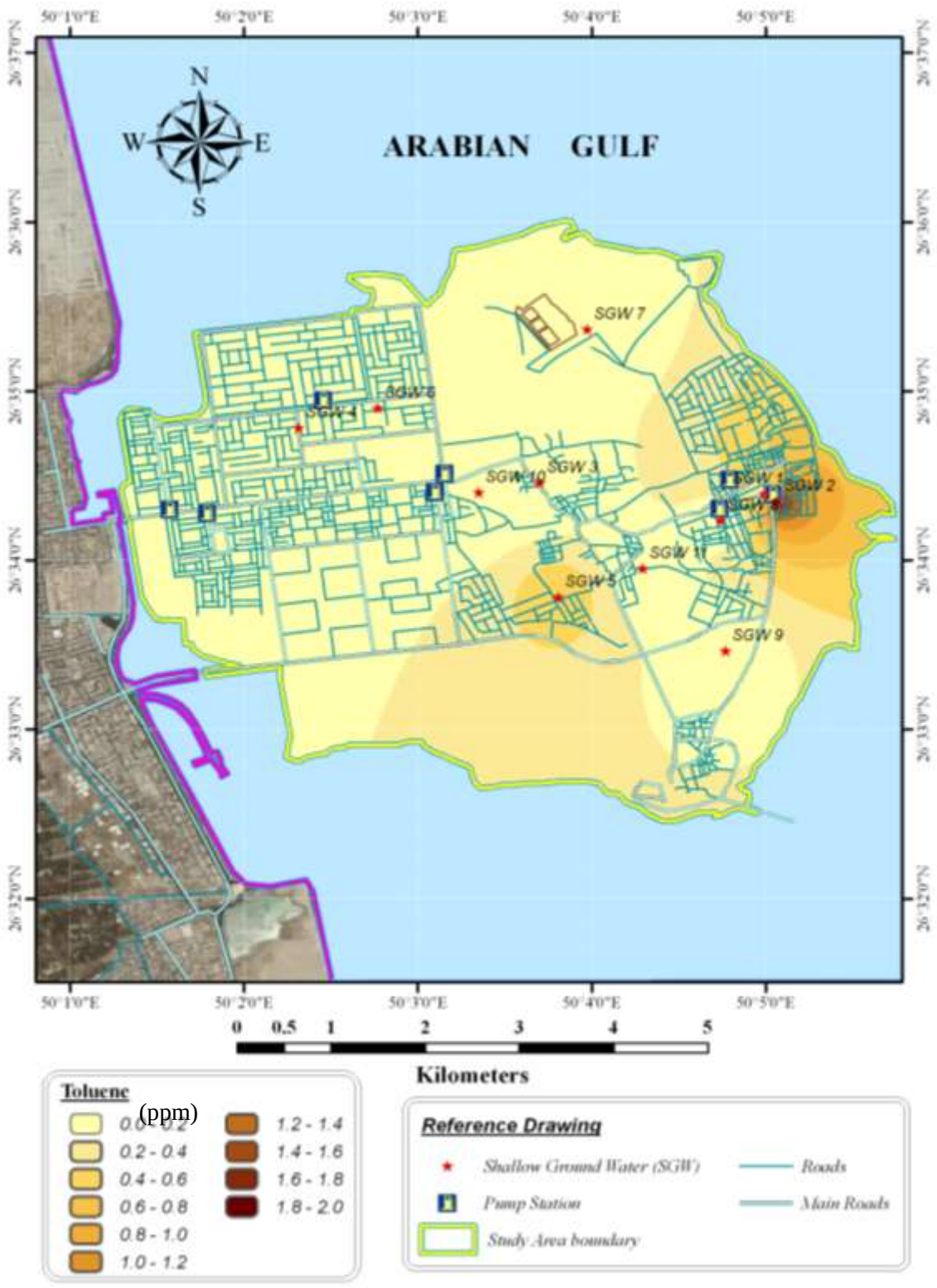


Figure 35: Toluene concentrations (ppm) distribution in shallow groundwater samples

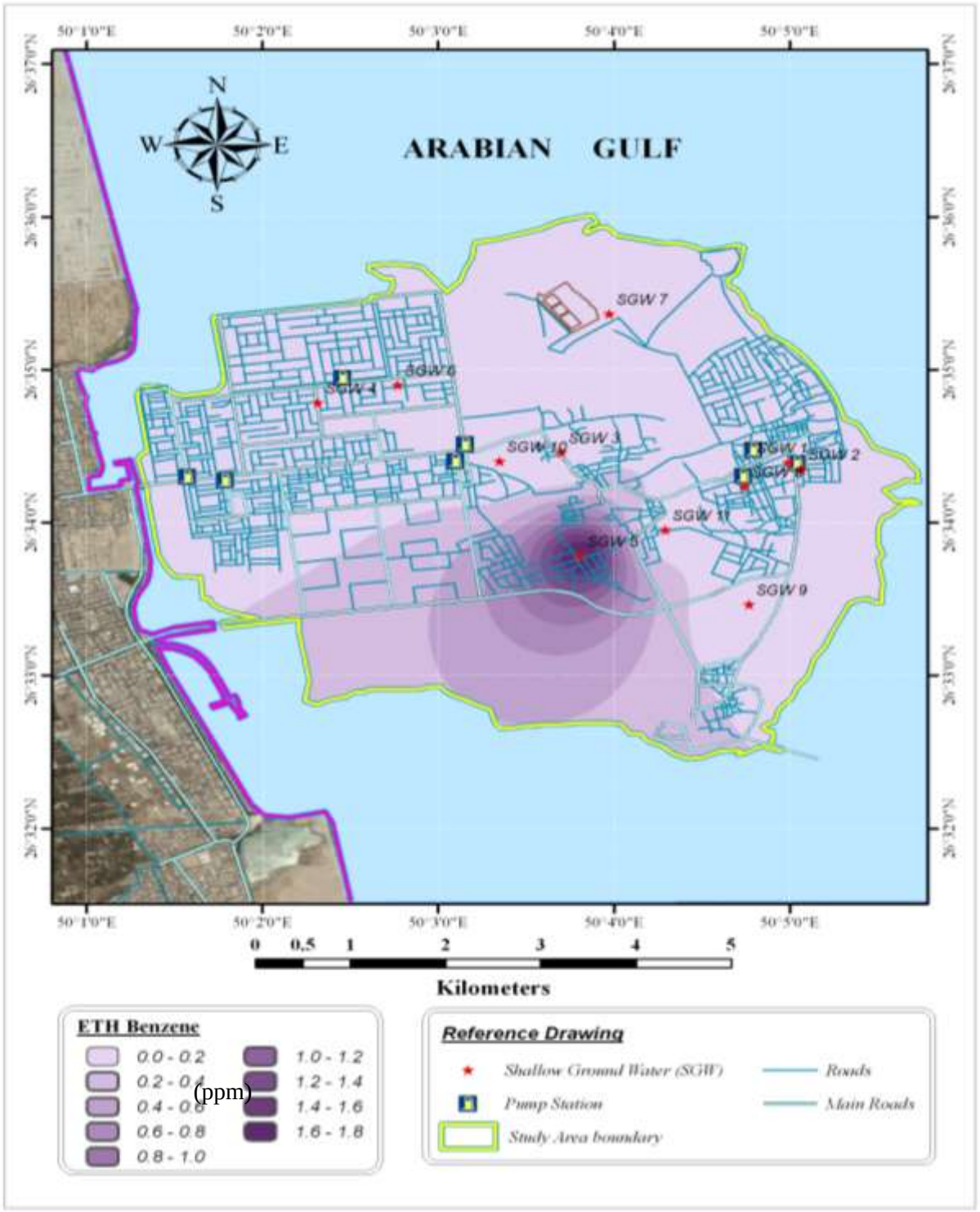


Figure 36: Ethylbenzene concentrations (ppm) distribution in shallow groundwater samples

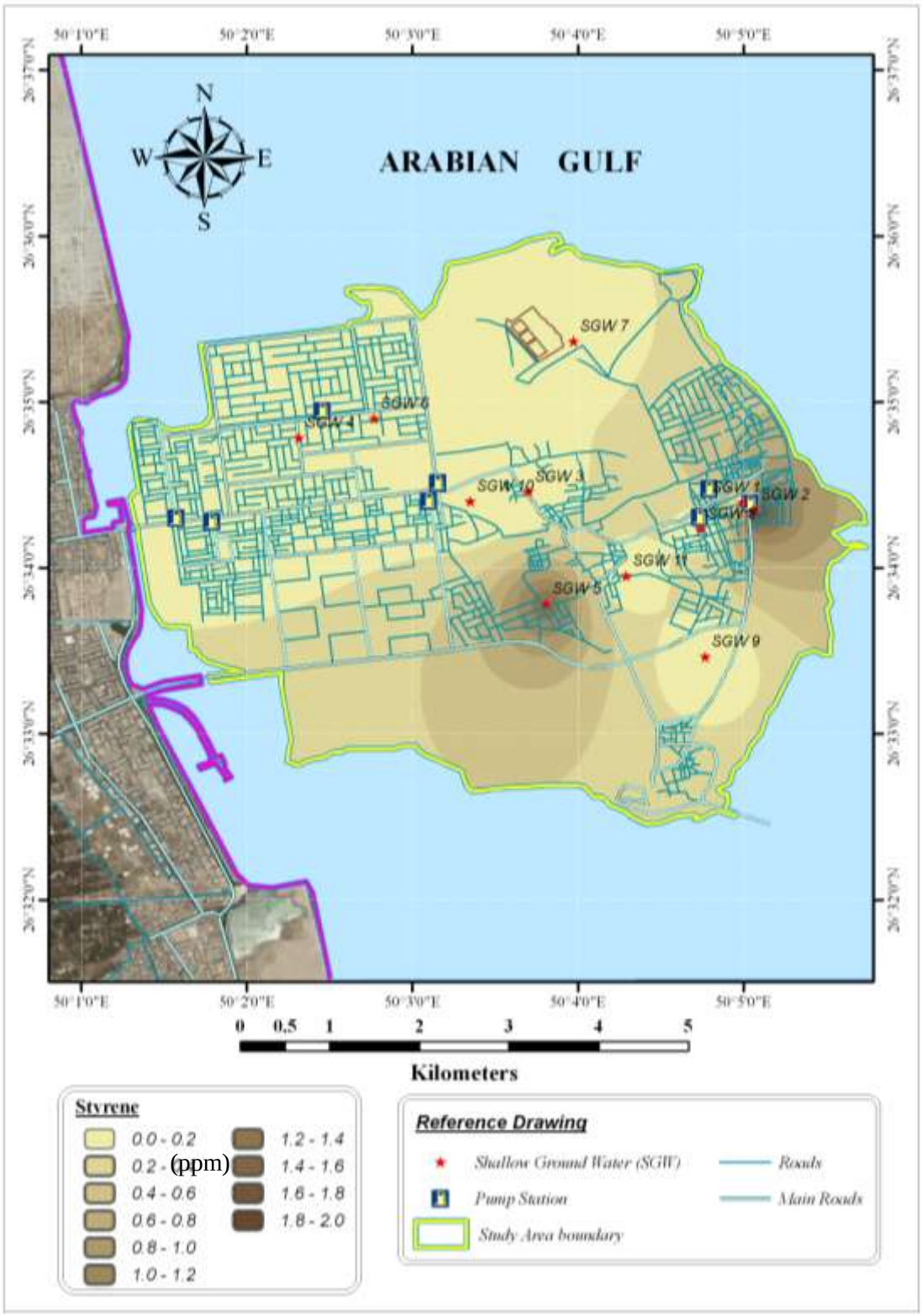


Figure 37: Styrene concentrations (ppm) distribution in shallow groundwater samples

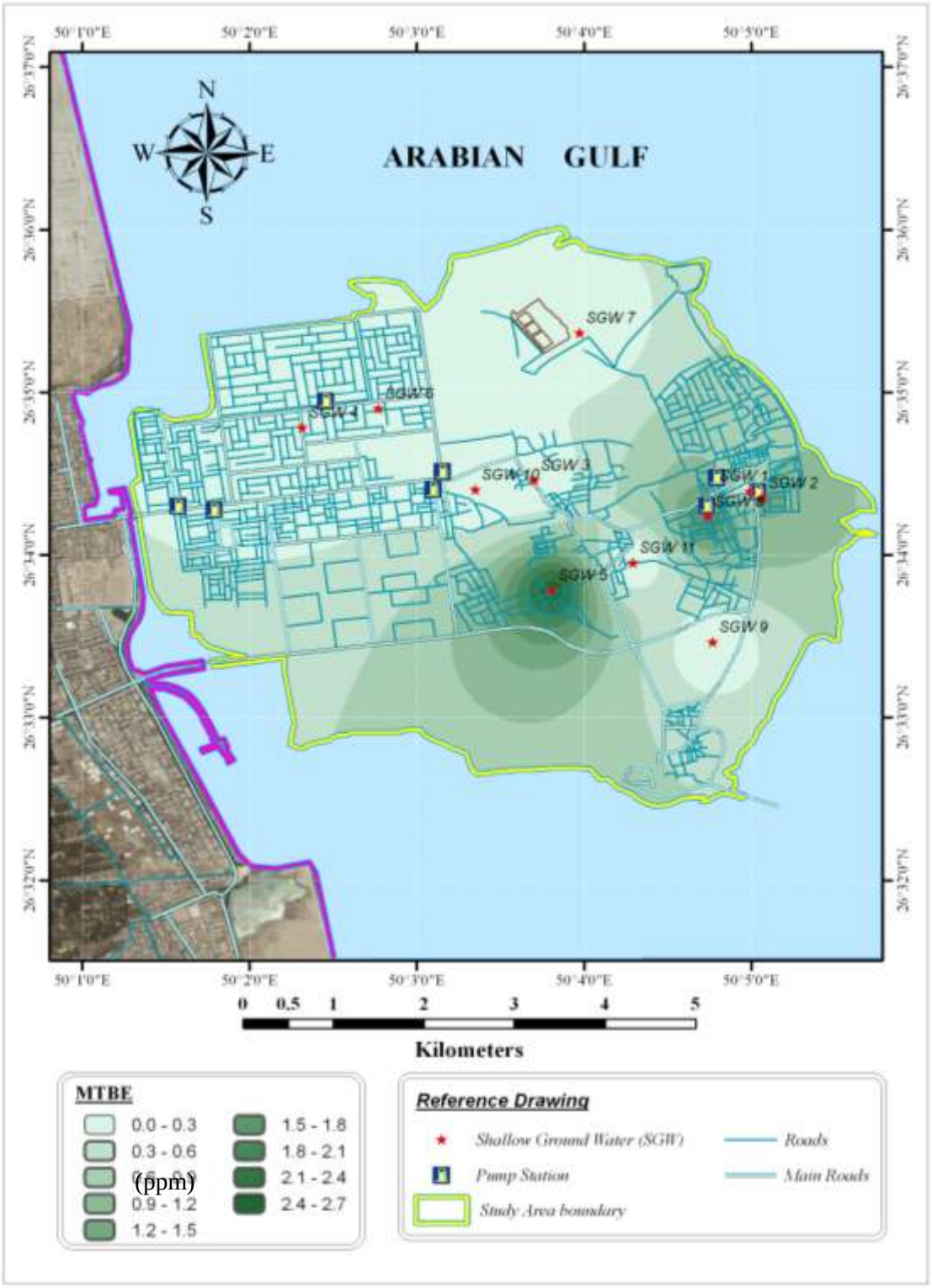


Figure 38: MTBE concretions (ppm) distribution in shallow groundwater samples

5.3 Assessment of Deep Groundwater

Seventeen (17) samples were collected from deep groundwater from different wells over the study area. The purpose of analyzing water from this layer is to determine the affect of contaminants on the groundwater quality. In the following sections, the contaminants that exceed the maximum allowable limit will be presented. The analysis data of groundwater samples are shown in Tables 6, 7, 8 and 9 in appendix A.

5.3.1 Biological Analysis

The main source of biological contamination is from human and animal waste, or waste water. In general the groundwater becomes contaminated due to the following sources:

- Land disposal of sewage from central treatment facilities or septic tanks.
- Leachates from sanitary landfills
- Fertilizers used in the farms.

(a) Total Coliform (TC)

Coliform bacteria are organisms normally found in the digestive tracts of livestock, humans, and birds (Hem, 1985). Total coli form (TC) bacteria are used to assess the quality of the drinking water because they can be correlated with water-borne diseases. Pathogenic microorganisms present the most significant threat from the consumption of groundwater contaminated by untreated sewage water (Yates and Yates, 1993).

Total coliform was detected in 18% of the samples in the study area. TC concentration in deep groundwater wells exceed the standard value: USEPA maximum contaminant level (MCL) of total coliform in drinking water for bacteria is 1col/100ml. The maximum total coliform detected in well 2 was about 10/100 ml. This indicates that this water is not suitable for drinking without treatment. Two wells out of the three contaminated wells are located very close to the waste water basin (surface water) in the industrial area. The bacteria detected in this study probably are possibly related to from the old sewage pipelines to the groundwater aquifer. This was reflected on the spatial variation map of total coliform (Figure 39).

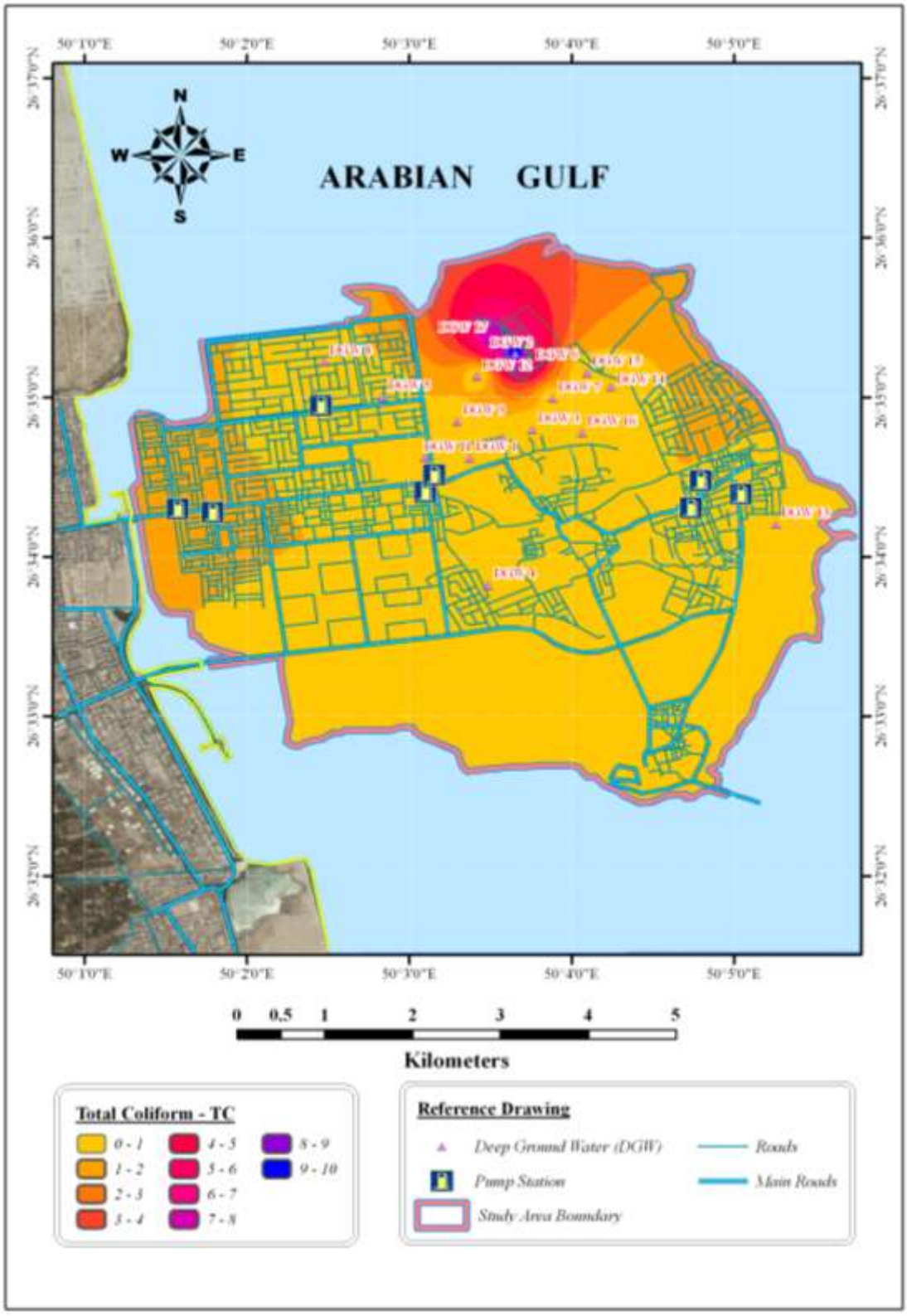


Figure 39: Spatial distribution of total coliform in deep Groundwater samples

(b) Chemical Oxygen Demand (COD)

Chemical Oxygen Demand (COD) is another important indicator of water quality assessment because it is indirectly used to measure the amount of organic compounds in water, making COD a useful measure of water quality. EPA standard value for drinking purpose is 4 ppm. The deep water analysis shows that 17 % of the samples collected from deep groundwater wells exceed MCL of COD. The maximum concentration was detected in well 6 which is very close to the municipal wastewater station (Figure 40). Though 83 % of sampled wells are within the allowable limit, some of them are very close to the MCL for COD such as well 7 where the COD value is equal to 3.4 ppm.

(c) Biochemical Oxygen demand (BOD)

Biochemical Oxygen Demand, or BOD, is a measure of the quantity of oxygen consumed by microorganisms during the decomposition of organic matter. BOD is the most commonly used parameter for determining the oxygen demand on the receiving water of a municipal or industrial discharge (Khitoliyal et. al., 2009). BOD can also be used to evaluate the efficiency of treatment processes, and is an indirect measure of biodegradable organic compounds in water. As per the EPA the BOD value for drinking purposes should not exceed 0.2 ppm.

The BOD analysis for deep groundwater well shows that nine (9) samples out of 17 contain BOD above the EPA standard. The highest BOD was detected in well 6 of about 9

ppm. The contaminated wells are mainly located in residential area which explains the high content of BOD. The sewage system is very old and there is a possibility of leakage from sewage pipelines and also from the septic tank. The distribution map for BOD characterized again the central area as the main area for COD contribution and BOD increases toward the sea (Figure 41).

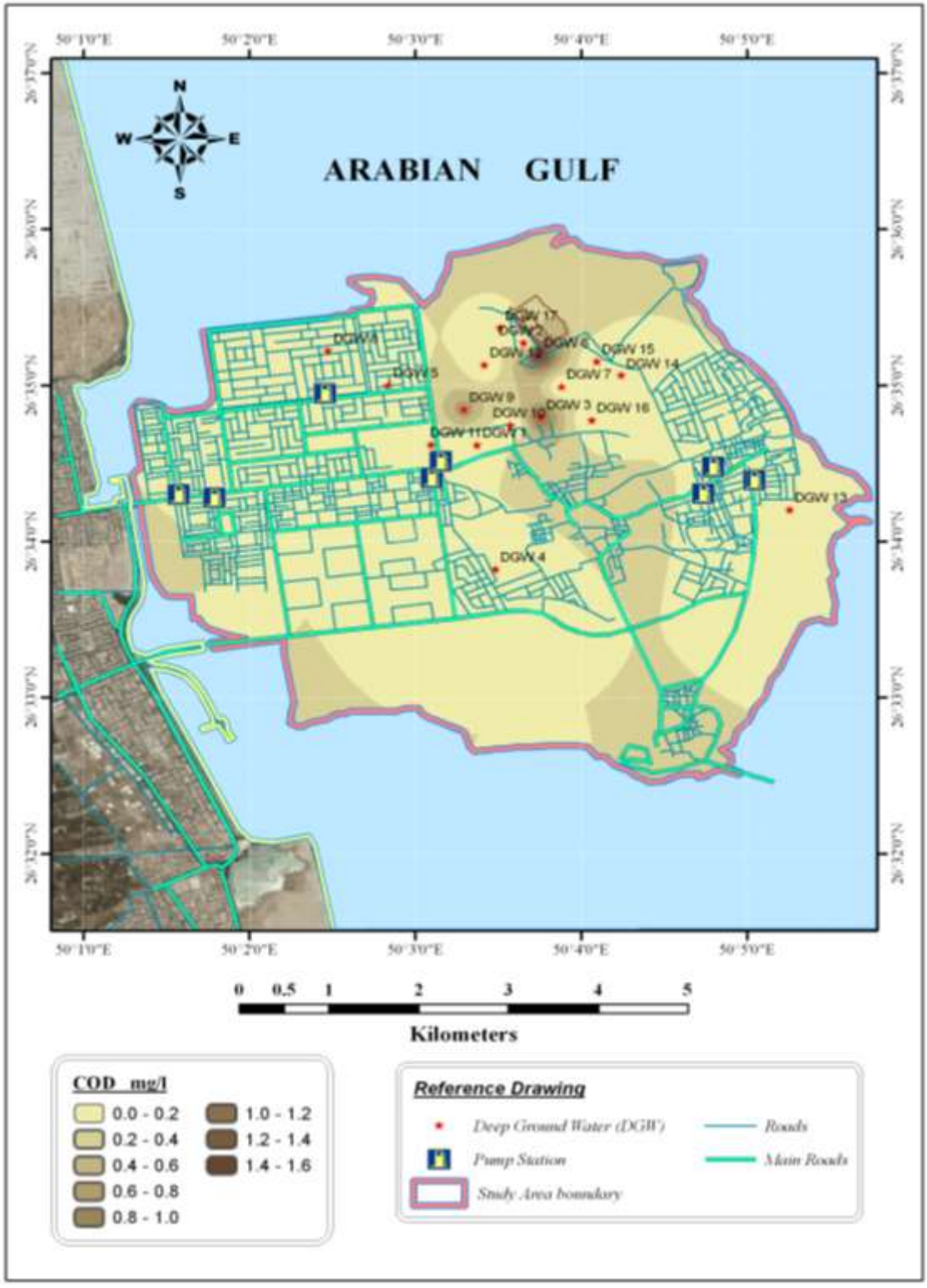


Figure 40: Spatial distribution of COD (ppm) in deep groundwater

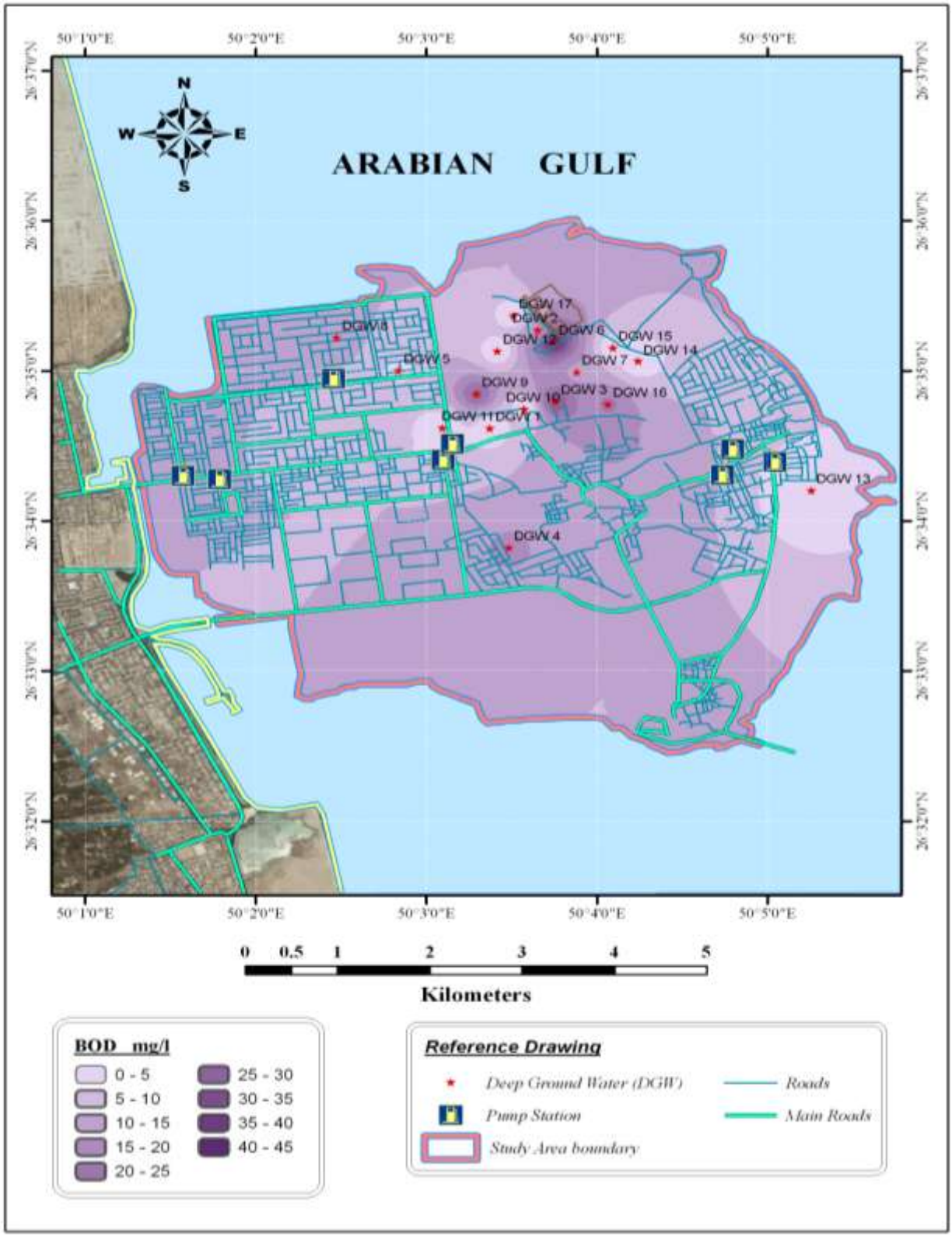


Figure 41: Spatial distribution of BOD (ppm) in deep groundwater

5.3.2 Chemical Analysis

Major ions that are normally considered in groundwater quality studies have been analyzed for groundwater in Tarout Island. In addition to that, the samples have been analyzed for some heavy metals and biological parameters.

(a) Iron

Since iron is the second most abundant metallic element in the Earth's outer crust (Hem, 1985), iron in groundwater may originate from a variety of mineral sources. Several sources of iron may be present in a single aquifer system. Several factors such as the oxidation potentials, organic matter content, and the metabolic activity of bacteria can influence the level of iron in groundwater.

The occurrence of iron in water leads to a metallic taste. The recommended secondary maximum concentration of Iron as per EPA in drinking water is 0.3 ppm. The iron level in water samples are equal or above the recommended value in most of the wells. The concentration of iron content in the groundwater of the deep aquifer varies between 0.3 to 1.0 ppm with an average value of 0.58 ppm.

Samples 7 and 10 which are collected from agricultural areas and samples 5 and 8 which are collected from industrial area and residential area show levels of iron above 0.3 ppm.

The spatial variation of iron over the study area is shown in Figure 42. Three hot spots of iron were detected in the central area at samples 7, 9 and 10. There is a possibility of direct contact between the shallow groundwater and the deep groundwater either through the wells the casings of which are very old or due to fracture between the two aquifers. The presence of iron content in the groundwater has already been mentioned in the discussion of shallow water condition.

(b) Lead

Another important contamination element is lead (Pb^{2+}). The recommended maximum limit for lead in drinking water as per the EPA is 0.015 ppm. Lead was not detected in all samples collected from different areas in Tarout Island . However, in sample number 6 it reaches 0.01 ppm. Sample no 6 is located in the industrial area (Figure 43). The presence of lead in groundwater is probably due to the existence of direct contact between the shallow groundwater and the deep groundwater either through the wells' casing or due to fractures in the aquifer.

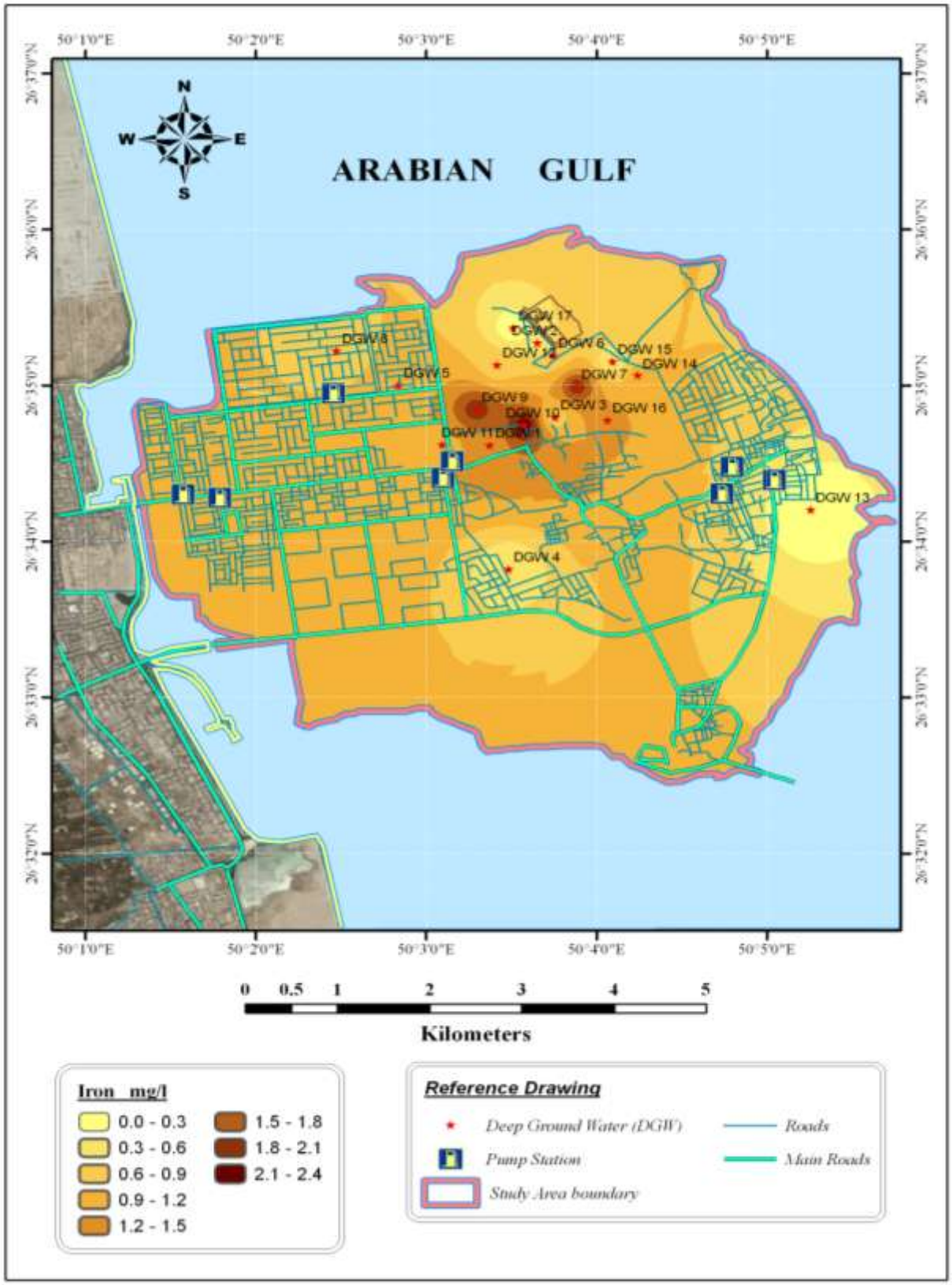


Figure 42: Spatial distribution of iron (ppm) in deep groundwater samples

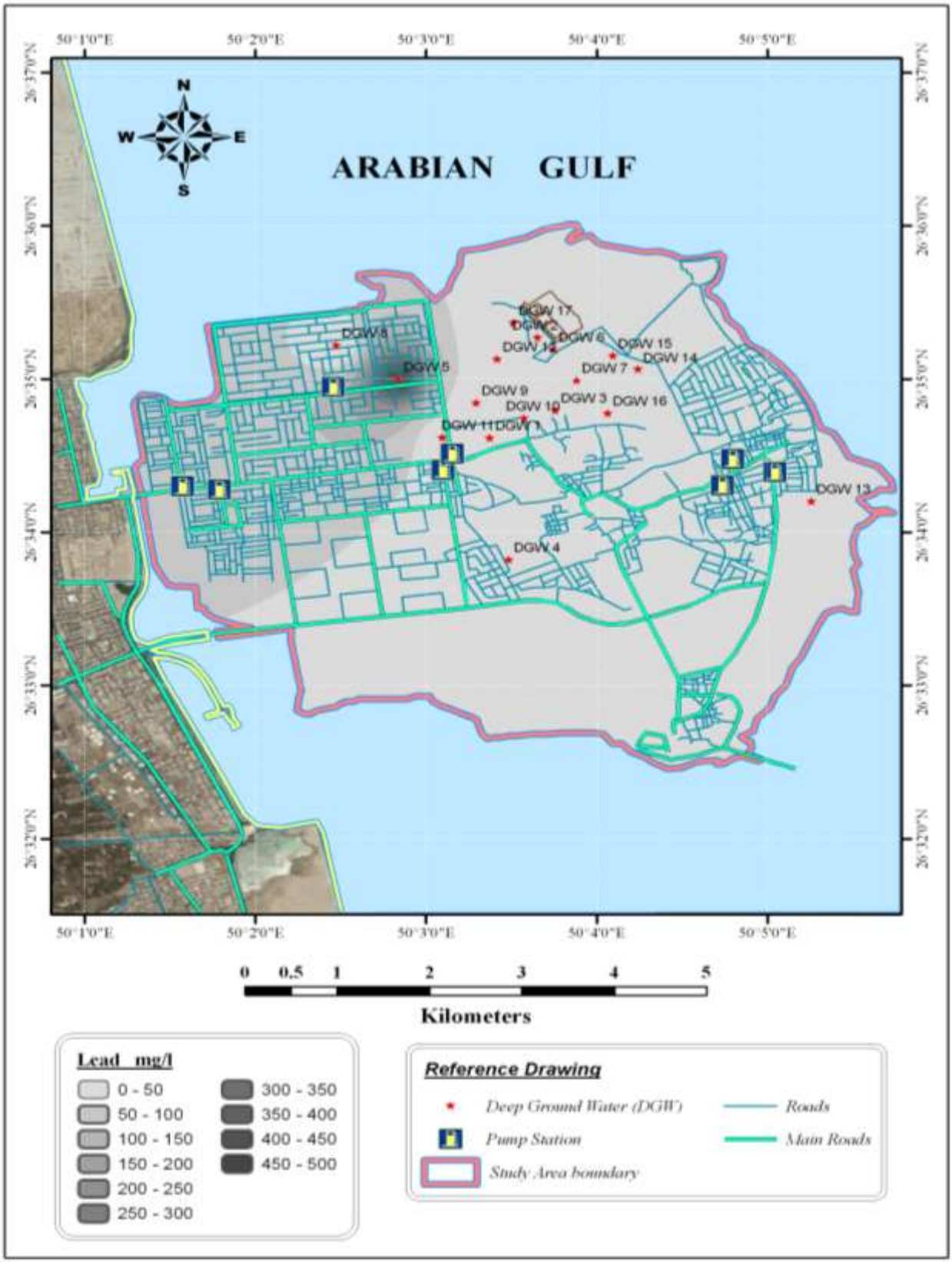


Figure 43: Spatial distribution of Lead (ppm) in deep Groundwater samples

(c) Hardness (Calcium and Magnesium ions)

Calcium and magnesium dissolved in natural water are termed as alkaline earth metals (Hem, 1985). They are naturally present in water in dissociated form as bivalent ions and are mainly responsible for hardness in water.

The calcium content ranges from 784 ppm to 3198 ppm, with an average value of 1501 ppm. The minimum calcium content was detected in the Eastern Region of Tarout Island in well 13 (Figure 44), whereas maximum was observed in the central region of the study area in well 22. There is no apparent relation between the calcium content and location of wells in the study area. The highest two points were located in the agricultural areas. The lowest calcium values are detected in wells 13, 14, 16, 17 and 21.

Magnesium values in the groundwater samples collected from deep aquifer wells are in the range of 272 to 691 ppm with an average value of 442 ppm. The lowest value of about 272 ppm was detected in well 12 in the agricultural area near the northern coastal belt (Figure 45). Magnesium concentration increases to 691 ppm in well 6 in the south of the study area which serves the agricultural area. The magnesium trend was not stable. It varies from one area to another. Hardness is related to the concentration of certain metallic ions in water, particularly calcium and magnesium and is usually expressed as ($CaCO_3$).

For the discussion purpose, it is useful to give some idea about the water classification in terms of hardness. Tchobanog et al (1985) developed the following classification: soft water from 0 to 50 ppm (as $CaCO_3$); moderately hard water ranges from 50 to 150 ppm; hard water from 150 to 300 ppm; and very hard water over 300 ppm. As per this classification the water in Tarout Island can be classified as very hard water (Figure 46). In general groundwater hardness levels are higher in the northeast part of the Island due probably to the presence of gypsum in the fractured thick Rus formation through which vertical flows from UER could occur (Rasheeduddin,1999). It also indicates the nature of rock types as dolomitic limestones (Rasheeduddin,1999).

(d) Total Dissolved Solids (TDS)

Total Dissolved Solids is measurement of the total salt content. The TDS of water samples collected from deep groundwater are very high. It reaches 3796 ppm. The secondary MCL level of TDS is 500 ppm.

TDS along the coastal belts along Qatif-Ras Tannurah, and Jubail was in the range of 3000-3500 ppm (Rasheeduddin,1999). By comparing the TDS measured in this study with the TDS measured before, slight increases in the TDS level is observed.

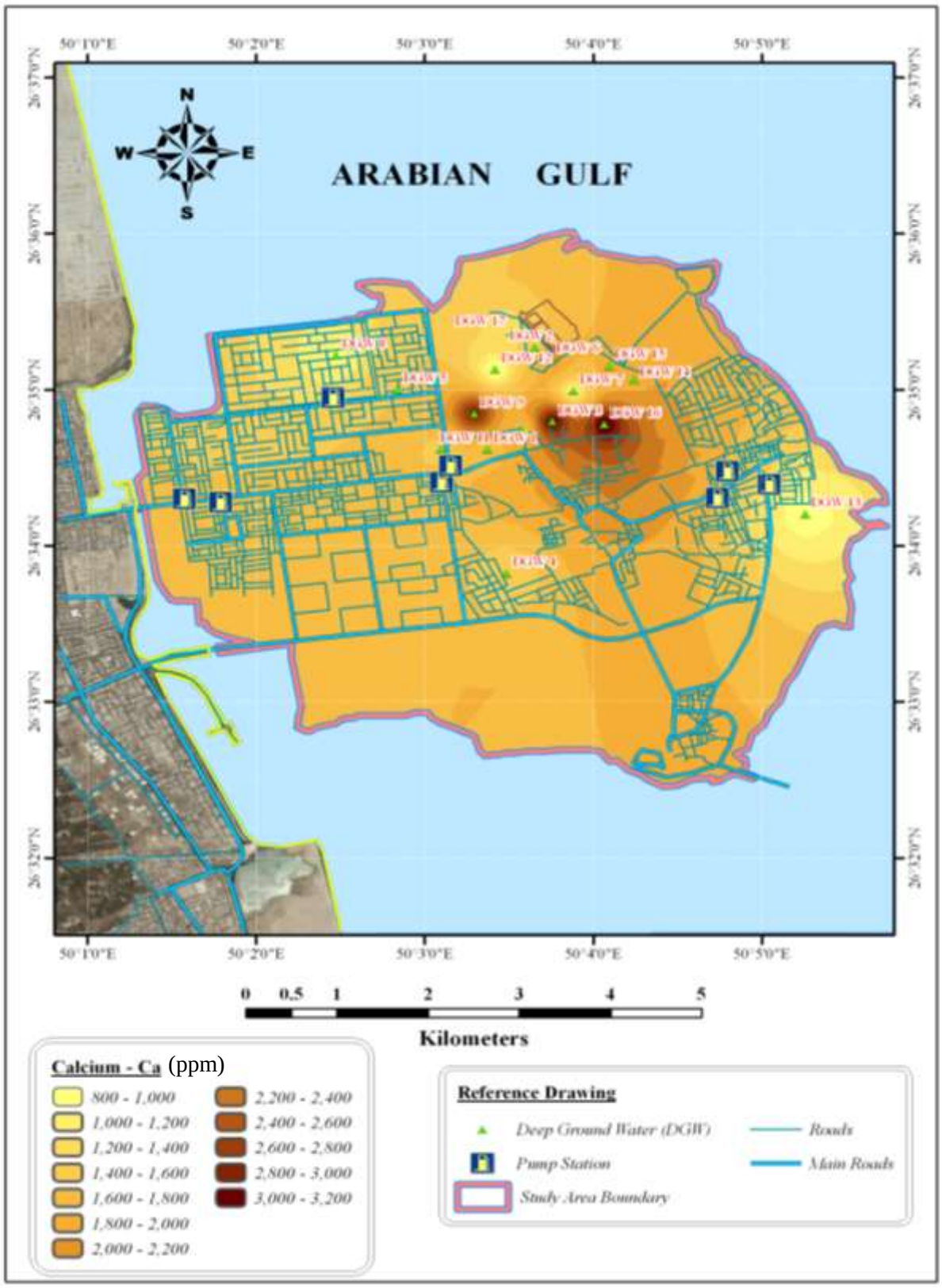


Figure 44: Spatial distribution of calcium (ppm) in deep groundwater samples

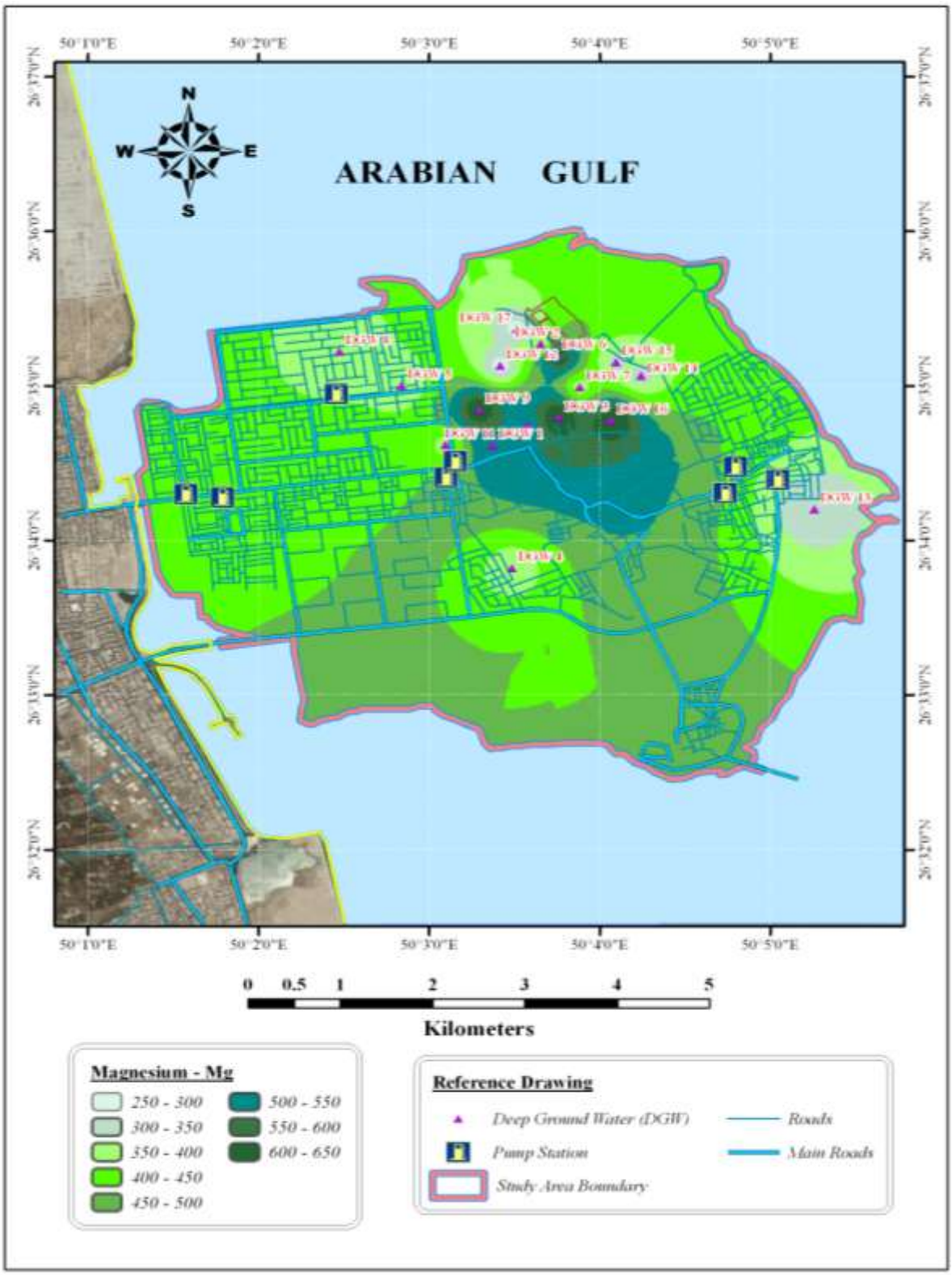


Figure 45: Spatial distribution of magnesium (ppm) in deep groundwater samples

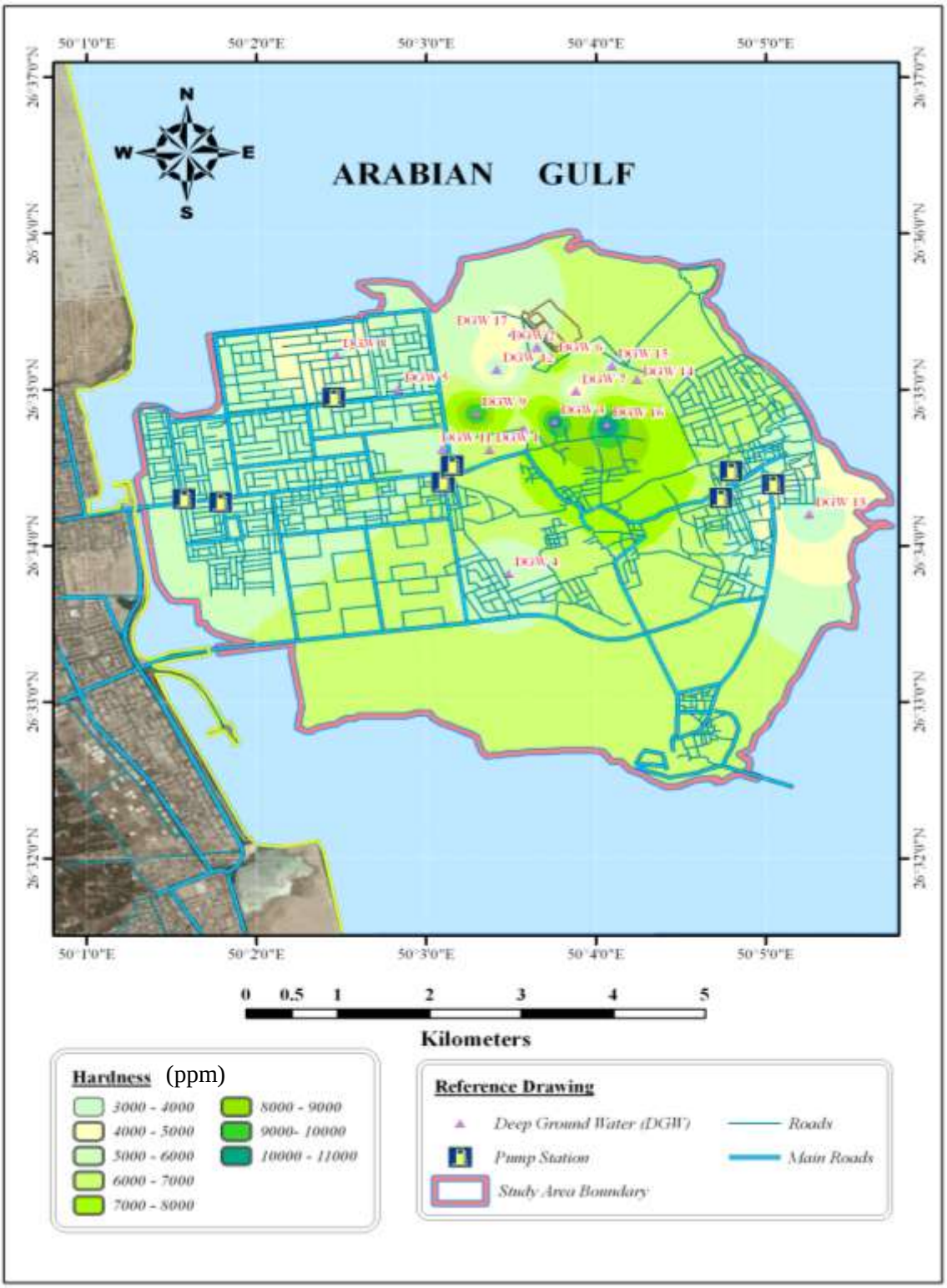


Figure 46: Spatial distribution of hardness (ppm) in deep groundwater samples

According to Rasheeduddin (1999) the reason of high TDS in some areas is the lithology and structural change in this region. The flow of groundwater towards the sea and slow movement of water horizontally and vertical flows to sabkahs may be related to the high salinity (Rasheeduddin,1999).

Figure 47 shows the spatial variation of TDS in the study area. Two major zones were identified with high TDS. They are located in the eastern part on the costal line and in the central parts or the old city area. The general trend is that the TDS increases towards the coast from west to east with some exceptional in the eastern part.

(e) Chloride

The presence of chloride in the groundwater is related to salinity. In natural groundwater, most chloride comes from evaporation, salty connate-water or due to the presence of shale that have lost chloride by leaching as a result of near surface exposure (Hem, 1985). The chloride is also a major indicator of septic system pollution (Alhajjar et, al., 1990).

Nevertheless, high chloride and sodium contents do not necessarily indicate connate water, but simply mean dissolution of soil and rock minerals and / or evapotranspiration of the runoff and irrigation water resulting in the concentration of salts. The average of chloride concentration in the samples collected from deep wells is about 2206 ppm. The majority of samples with high chloride content are located in the central and northern parts of Tarout which is mainly an agricultural area and very close to the sea water from

the north side. So these two sources might explain high content of chloride in the samples. The spatial distribution of chloride is shown in Figure 48.

Chloride is shown to be a conservative indicator of pollution from septic system, because chloride in leachate moves unattenuated with groundwater (Alhajjar et al., 1990). The highest chloride value was detected in well 7. The well is located in the agricultural area and very close to sewage treatment station. In view of the above, the high chloride may be attributed to the percolation of sewage waste.

(f) Bromide

Bromide content in groundwater in the study area ranges from 4 ppm to 10.1 ppm with an average value of 10 ppm. The high content of bromide in groundwater was found in sample DGW 6. There was no limit value for bromide in EPA regulation and standards, but bromate (BrO_3) in groundwater should not exceeded 0.01 ppm. the spatial variation of bromide is presented on Figure 49. The presence of bromide in groundwater has been discussed in assessment of shallow groundwater (section 5.2.3).

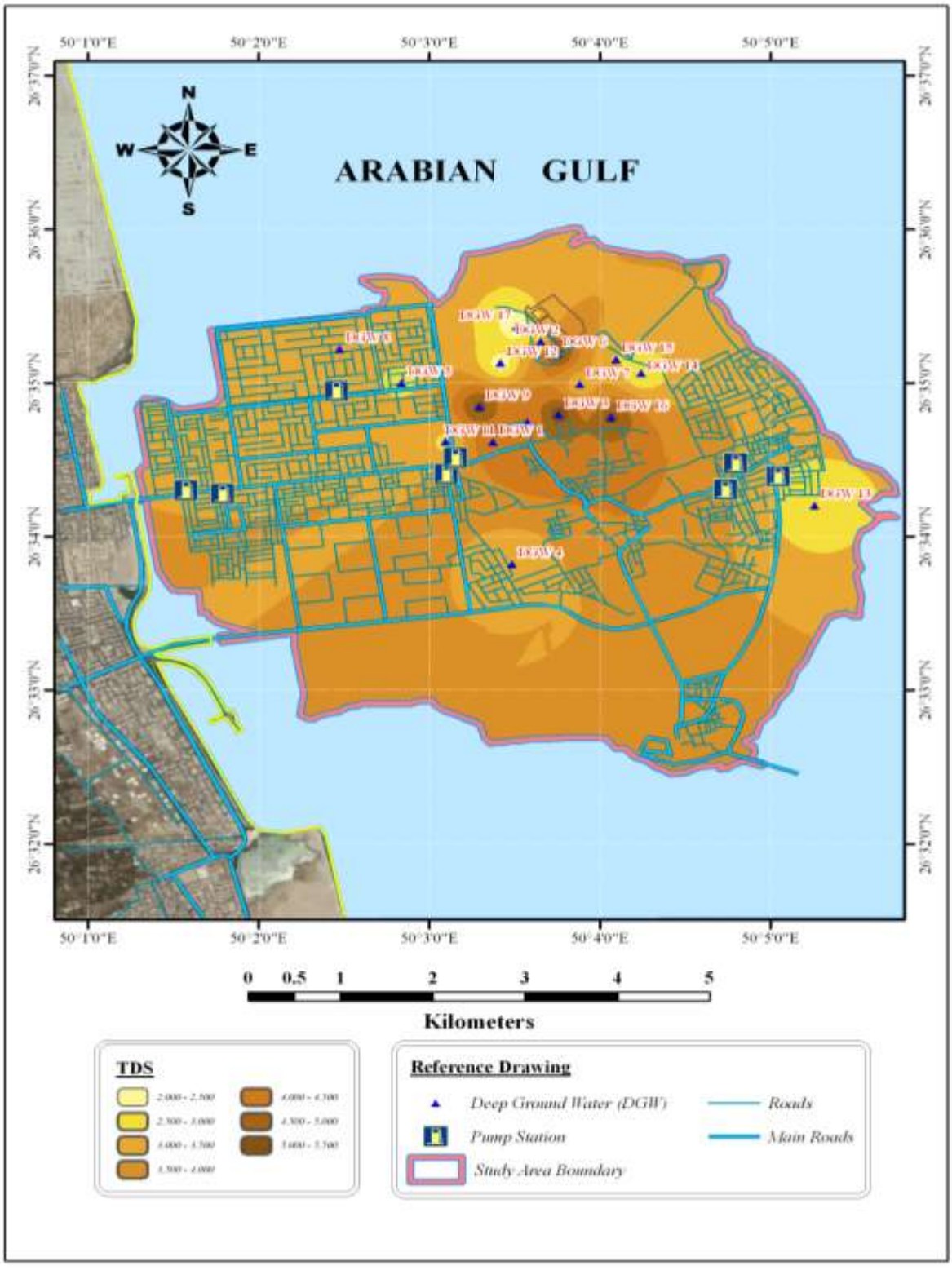


Figure 47: Spatial distribution of TDS (ppm) in deep groundwater samples

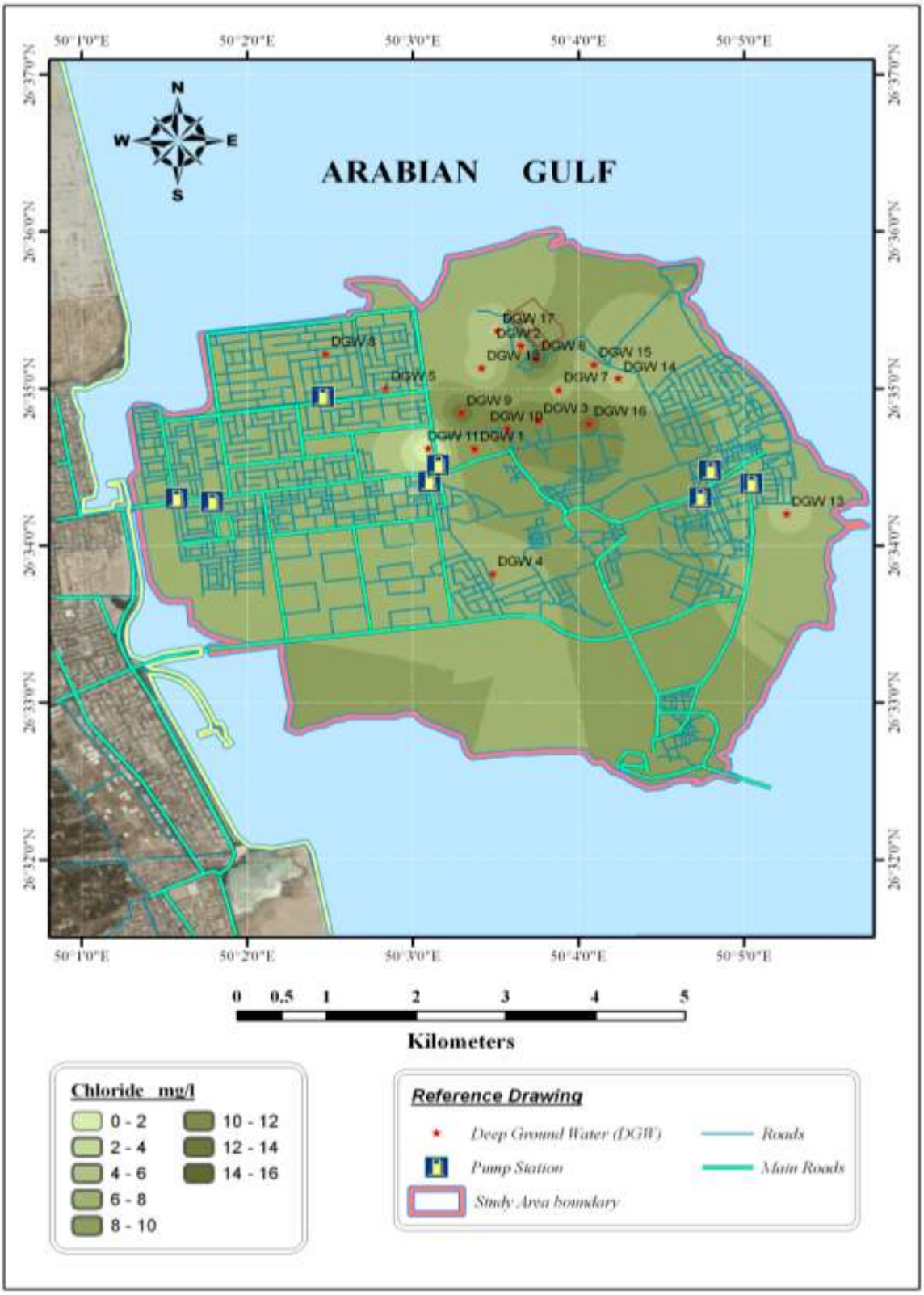


Figure 48: Spatial distribution of chloride (ppm) in deep groundwater samples

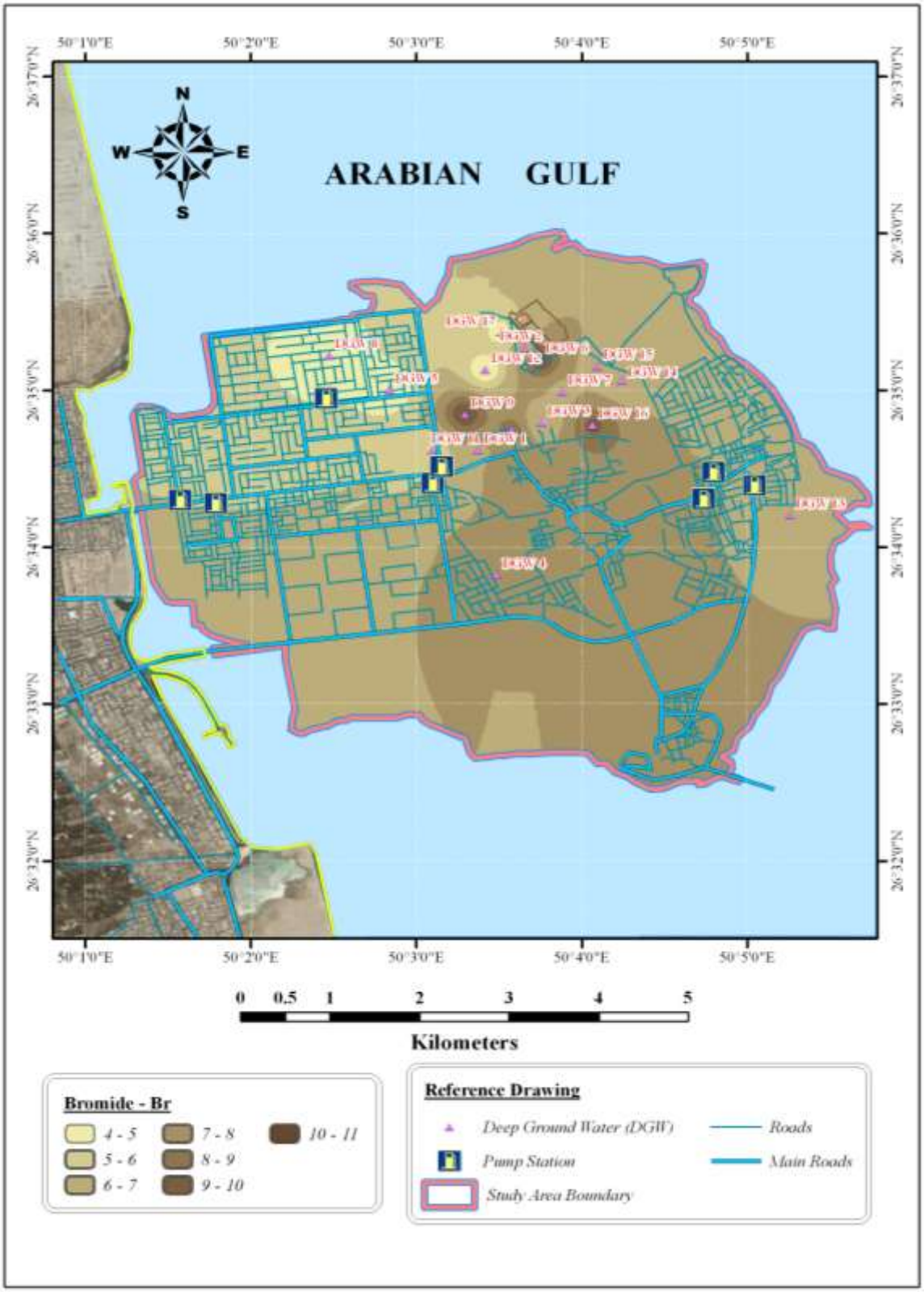


Figure 49: Spatial distribution of bromide (ppm) in deep groundwater samples

(g) Sulfate

Sulfate concentrations in the study area were found to be very high. The established secondary maximum contamination level (SMCL) by USEPA for sulfate is 250 ppm. In all samples the sulfate content was above the SMCL.

Sulfate concentrations in the deep groundwater samples range between 395 ppm and 1494 ppm with an average of 760 ppm. The highest content of sulfate in the samples collected from deep aquifer was detected in sample 7 which is located in the agricultural area (Figure 50) .

High concentrations of sulfate may be attributed to the structure and the lithology of the Dammam aquifer and Rus aquifer and dissolution of the gypsum present in the formation which is widely distributed in sedimentary rocks (Rasheeduddin, 1999).

Basically, sulfate available in groundwater as a result of the oxidation of sulfur in igneous rocks and the solution of other minor sulfur bearing minerals (Hem, 1985). Sedimentary rock may also yield large amount of sulfate through oxidation of pyrite (Mathhes, 1982). Another reason for high content of sulfate may be attributed to fertilizers and human influences. The spatial distribution of sulfate shows zones with high content of sulfate concentrated in the central area (agricultural area) toward the northern part. People not used to drinking water with high levels of sulfate can experience dehydration and diarrhea. Children are often more sensitive to sulfate than adults. As a safety measure, water with a sulfate level exceeding 400 ppm should not be used in the preparation of

baby food. Older children and adults become used to high sulfate levels after a few days (EPA,2004).

(h) Sodium

The sodium content in deep ground water is considered very high compared with the international standrads. USEPA has not published MCL of sodium in groundwater, so the Canadian standards (Health Canada, 2010) was used to assess the groundwater against sodium. The allowable limit of sodium is 200 ppm (Health Canada, 2010). Sodium concenteration in Tarout deep groundwater samples range between 443 ppm and 1313 ppm., The analysis of sodium in deep aquifer water shows very high content of sodium. The highest was detected in sample DGW 6 wich is located very close to the coast as well as to the sewage treatment station. This may be attributed to agricultural activities and leakage from a sewage system as well as the municipal wastewater treatment station. This is suported by the information listed in water stewardship information series published in 2007 (B.C.'s Ground Water Protection Regulation, 2007). It refers the high content of sodium in groundwater to several factors as listed below:

- Erosion of salt deposits and sodium bearing rock minerals
- Naturally occurring brackish water of some aquifers
- Salt water intrusion into wells in coastal areas
- Irrigation and precipitation leaching through soils high in sodium
- Groundwater pollution by sewage effluent
- Infiltration of leachate from landfills or industrial sites

The spatial variation of sodium level in the study area again shows that the agricultural area is characterized by very high sodium (Figure 51).

In general, sodium at low level is not considered harmful but increased intake of sodium in drinking water may cause problems to people with hypertension, heart disease or kidney problems (EPA, 2004).

(k) Potassium

The presence of potassium in groundwater primarily results from the chemical decomposition of feldspar and some mica. Other sources of potassium in groundwater are from contamination of agricultural by-products and industrial influence (Hem, 1985). Potassium concentrations in deep groundwater samples range between 28.3 ppm and 69.1 ppm. Thus, the high concentrations of potassium in the study area, especially in the central part can be attributed to the effects of agricultural and industrial activities, as well as sewage water. Spatial variation of potassium in the study area is shown in (Figure 52).

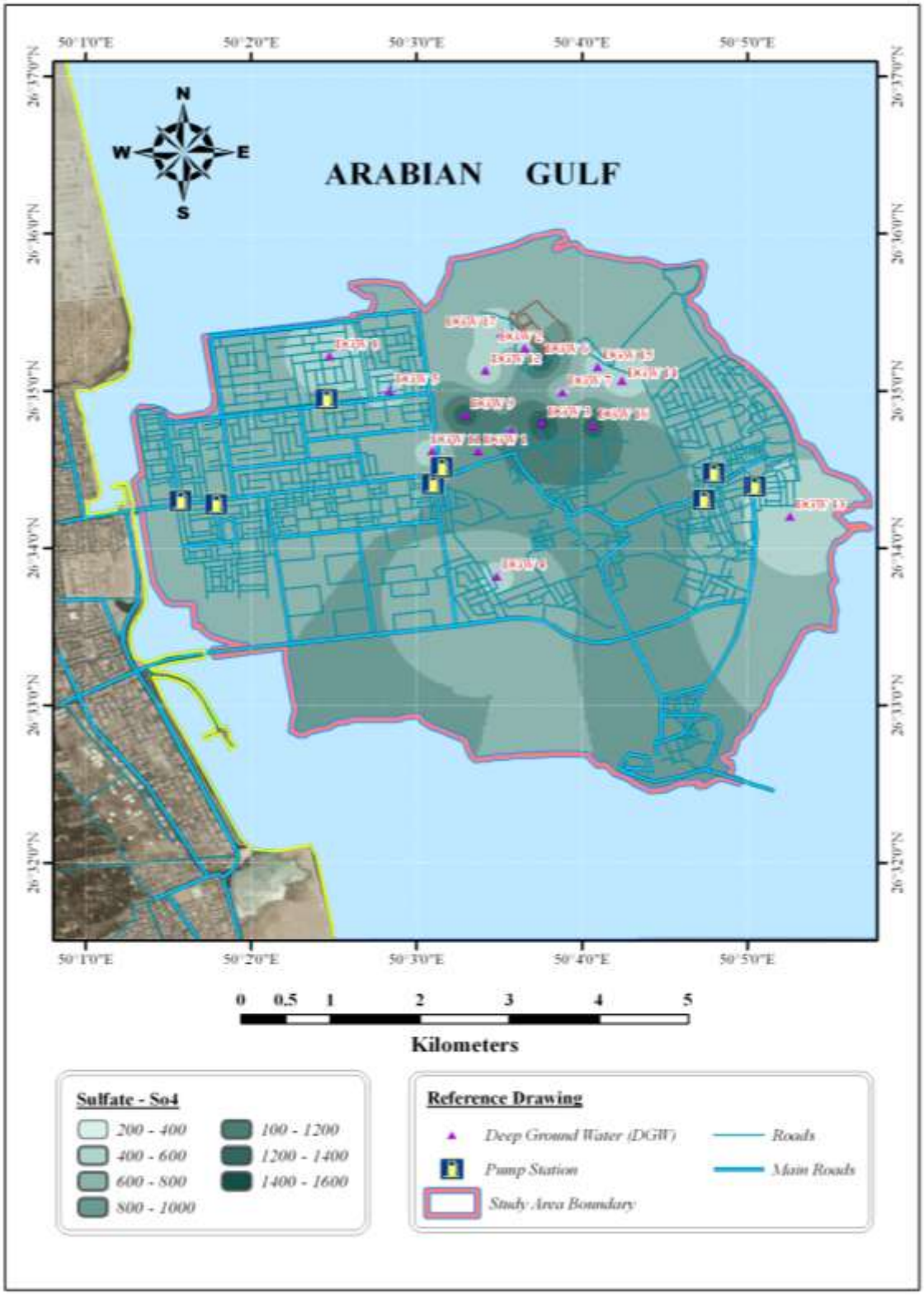


Figure 50: Spatial distribution of sulfate (ppm) in deep groundwater samples

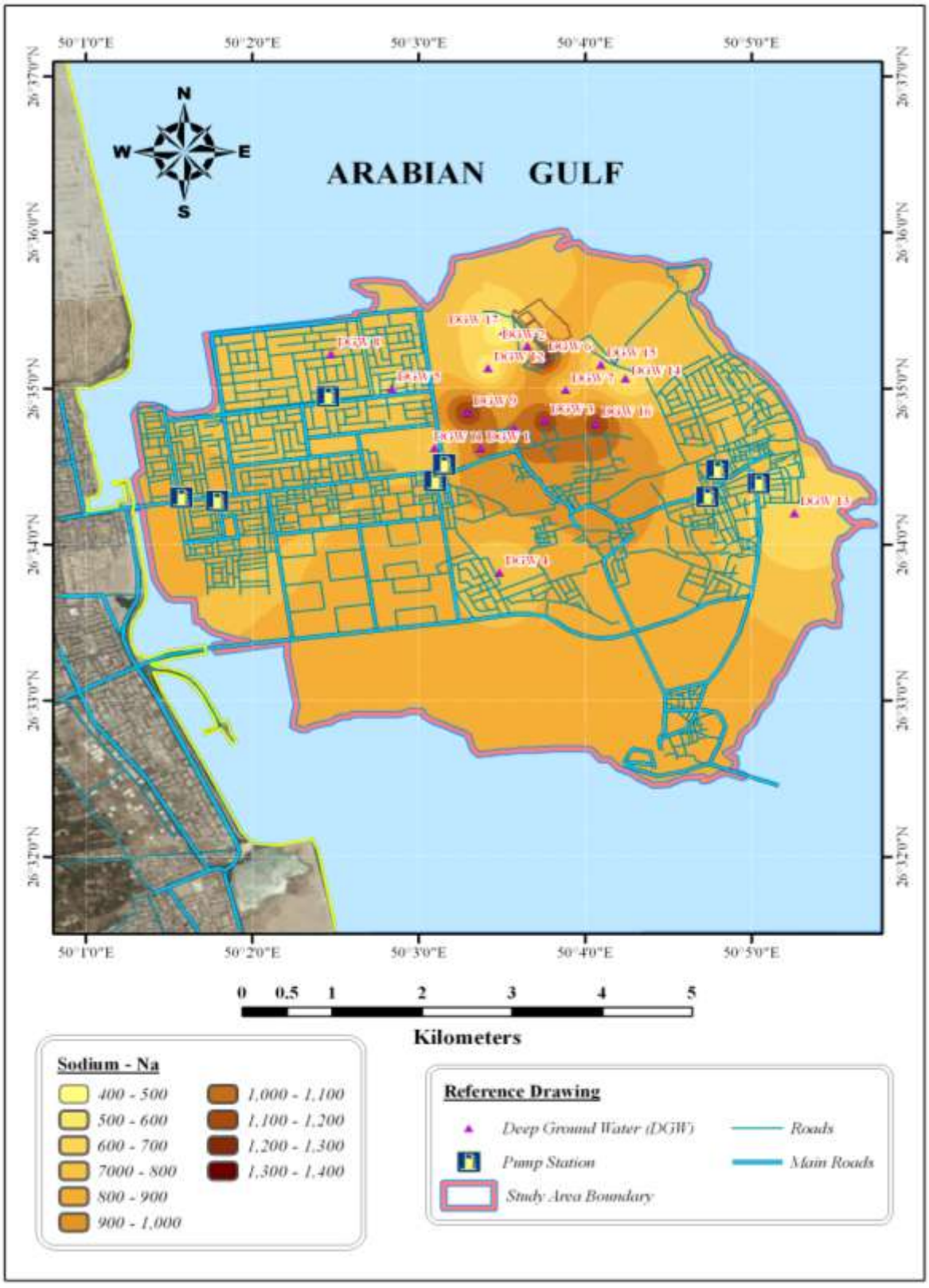


Figure 51: Spatial distribution of sodium (ppm) in deep groundwater samples

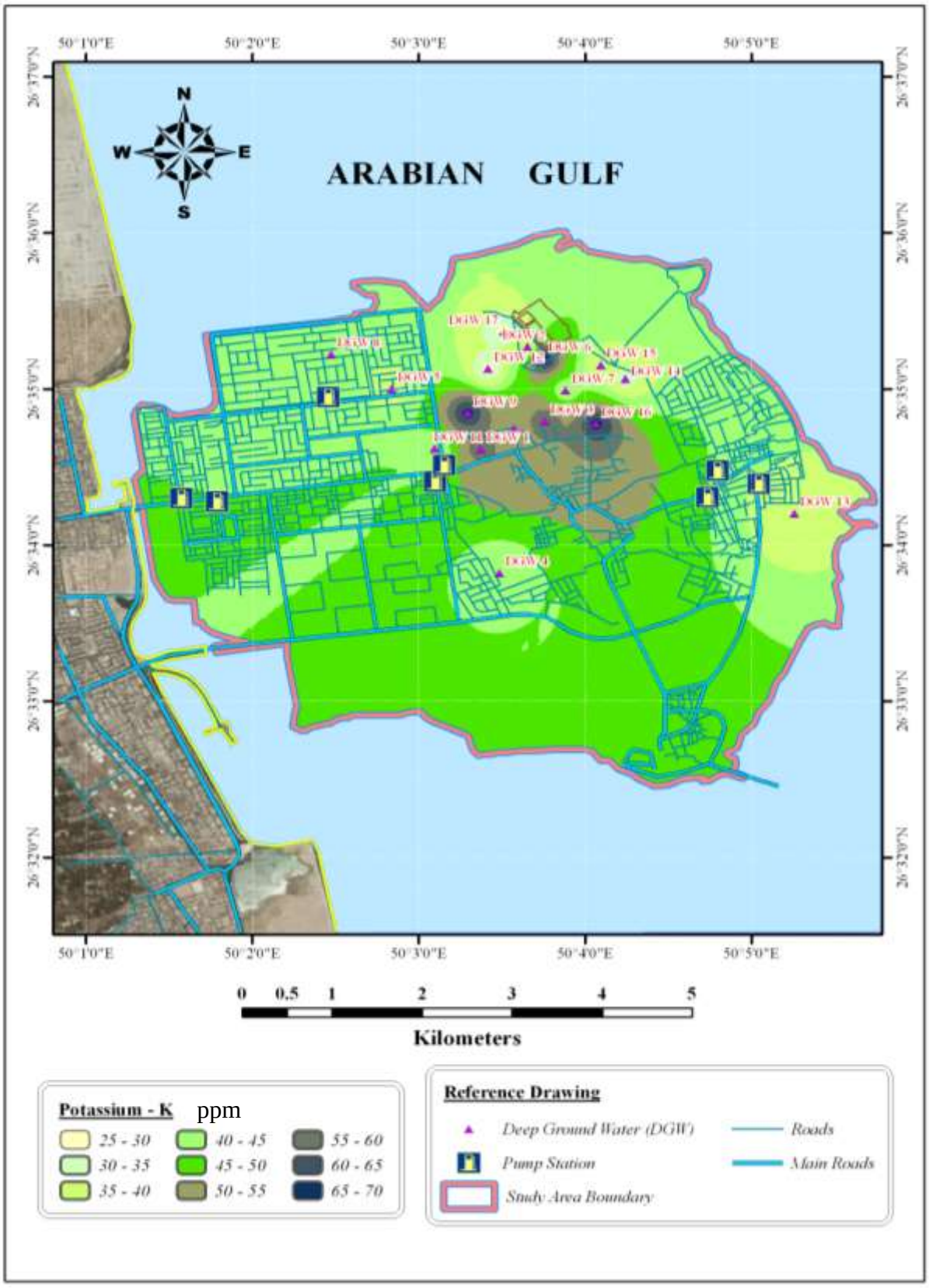


Figure 52: Spatial distribution of potassium (ppm) in deep groundwater samples

(l) Phosphate

The deep water analysis shows very high content of phosphate. Elevated levels of phosphate in deep water can be attributed to the seepage from the sewage system and application of fertilizers. Phosphate concentrations in groundwater in the study area range between 0.1 ppm and 29 ppm. It was not detectable in most of the samples. The two highest phosphates content were found in samples DGW 17 and DGW 2. Both samples are located in the agricultural and residential area. The high value may be attributed to the leakage from septic tanks since this area was not covered by sewage system for more than 20 years. However, sample number DGW17 is located in an agricultural area which might be attributed to the irrigation return water. Spatial variation of phosphate in study area is shown in Figure 53.

(m) Nitrate & Nitrite

Nitrate is one of the most commonly used indicators of contamination of groundwater from septic system (Flipse et.al., 1984; Heam, 1989). The majority of the deep ground water samples were above the MCL of 10 ppm. The highest content of nitrate was found around 43 ppm in DGW 7. Only 3 wells (DGW 6, DGW 8, and DGW 15) out of the 23 wells were found to have nitrate levels within these regulations. However, they are very close to the MCL value.

The analysis of deep ground water shows that wells 2, 6, and 17 have nitrite of 5 ppm, 6.5 ppm, and 2.5 ppm respectively. Well 7 has the highest concentration of nitrite which is about 6.5 ppm, whereas the MCL value is 1 ppm. This may be due to the runoff from agriculture activities and leakage from the wastewater treatment station. This was expected and most probably caused by the combination of long term cultivation in the same soil and the runoff of wastewater to the aquifer. Nitrates are produced during the final stage of decomposition of organic matter (Carter and Sneed, 2001) and are the most prevalent forms of nitrogen in groundwater (Hem, 1985).

The residence of nitrogen compounds indicates the presence of organic matter. Nitrogen fixing plants, bacteria, chemical fertilizers, sewage and septic tank discharge are the principal sources of nitrate in water (Flipse et.al., 1984; Heam, 1989). Agricultural activities result in nitrate contamination of groundwater with concentrations in shallow aquifers commonly exceeding the drinking water maximum contaminant level of 10 ppm (Bohlke, 1995). The same study concluded that the groundwater in arid areas commonly have relatively high NO_3^- content of apparently natural origin, derived from weathering of nitrogen-bearing rocks, degradation of organic matter in soils, or atmospheric deposition.

Nitrate contamination for the current study cannot be attributed to a specific source. Tarout Island is heavily cultivated. Sewages leaks are common due to the old sewages system and very classical septic tanks. Agricultural activities which cause deterioration of the groundwater quality are mainly the source of nitrates in groundwater especially in the old town in the central and in the eastern part of the study area. Nitrogen is very soluble in water (Sikora and Keeney, 1975). About 30 % of it are observed by plant and the rest

goes into solution with drainage water in which the nitrate ions can easily reach the groundwater through the soil since absorption in the soil is very low (Sikora and Keeney, 1975). Figures 54 and 55 show the spatial variation of nitrate and nitrite in the study area.

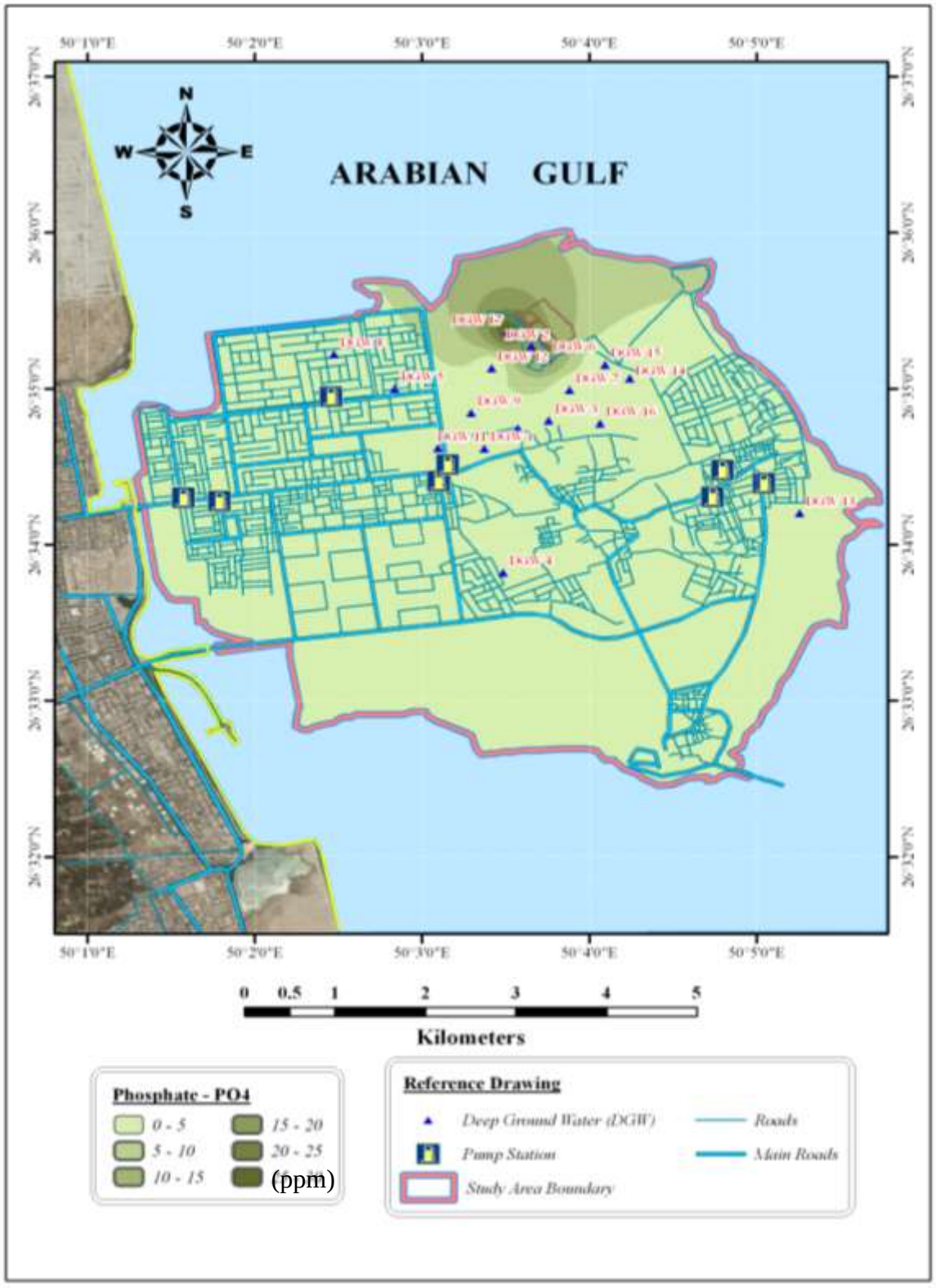


Figure 53: Spatial distribution of phosphate (ppm) in deep groundwater samples

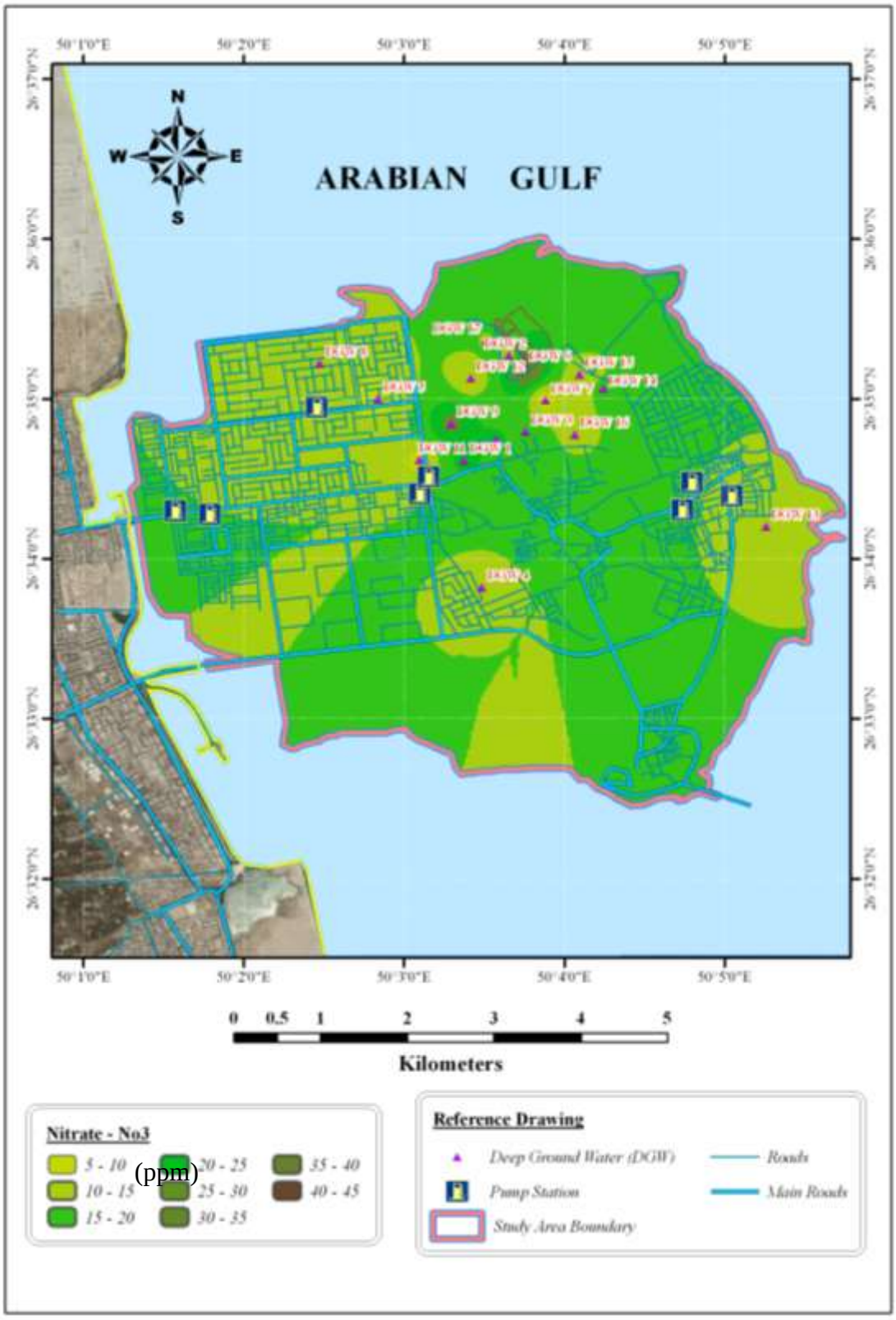


Figure 54: Spatial distribution of nitrate (ppm) in deep groundwater samples

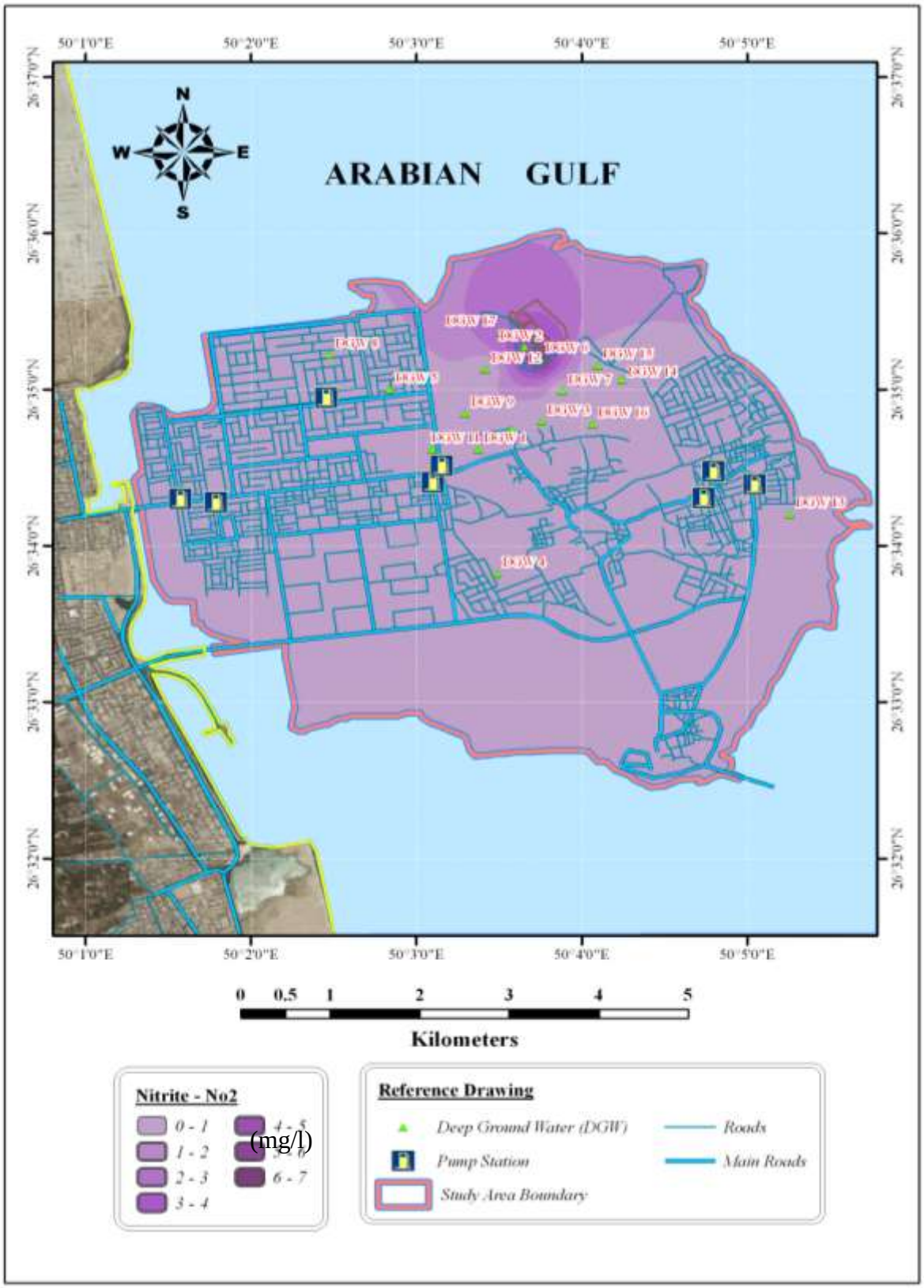


Figure 55: Spatial distribution of nitrite (ppm) in deep groundwater samples

5.3.3 Hydrocarbon Analysis

There were no indications of groundwater contamination by hydrocarbons. The deep groundwater analysis has not detected hydrocarbon compounds in any of wells. But we need to have close monitoring of deep groundwater quality since the shallow groundwater is already contaminated with some of hydrocarbon compounds. There is a possibility of contaminated shallow groundwater to be transported to the deep groundwater supply.

CHAPTER 6

RISK ASSESSMENT

One of the objectives of this study is to calculate the risk index of each contaminant exceeding the standard limit so the following sections will concentrate only on the parameters higher than the MCL values set by EPA.

6.1 Scope of the Assessment

The scope of the assessment is to identify the environmental impacts caused by the contamination sources and to rate the impacts as significant or insignificant by indexing the risk in values ranging from 0 to 1. Risk index is calculated as a ratio of analytical concentration of the element in the environment (AC_i) to the risk concentration (RCi) or the maximum allowable limit (MCL_i) with no adverse effect on the system:

$$I_{ERi} = AC_i / RC_i \qquad (6.1)$$

where

I_{ERi} = Index of environmental risk of element i

A_{Ci} = Analyzed concentration of element i

R_{Ci} = Risk concentration of element i

No or low risk is documented if the I_{ER} is less than 1. if the I_{ER} is higher than 1, there is elevated environmental risk in the area being investigated. Environmental risk is designated then by the index of environmental risk, which is called relative risk score. Its numerical value predicts the probability of the occurrence of negative impact on the environment via specific contaminants (Anon, 1994a, 1998a).

The guidelines stipulated by the European Union, particularly Commission regulation (EC) No. 1488/94/ES, lays down the principles for the assessment of the risks of existing substances to man and the environment (Anon 1994a). Consequently, ecological or environmental risk assessment is targeted according to the evaluation of contamination levels in individual environments.

So based on the results received in investigation carried out in Slovakia, the following scale of environmental risk assessment level was determined:

- IER = 0 no risk
- $0 < IER \leq 1$ low risk
- $1 < IER \leq 3$ medium risk
- $3 < IER \leq 5$ high risk
- IER > 5 very high risk

So if the ratio is less than 1, no risk is documented, while on the other hand, if the ratio is higher than 1, there is elevated environmental risk in the medium being investigated. Environmental (ecological) risk is designated then by the Index of environmental risk, which states the so-called relative risk score. Its numerical value predicts the probability of the occurrence of negative impact on the environment via specific contaminants. The total effect of several elements with excessive limit concentrations can be expressed as a sum of the risks of individual elements. Calculation of the index of environmental risk (IER) for groundwater in the study area consists of the two following steps:

First step is to compute the index of environmental risk for each analyzed element or compound above the limit-risk value (I_{ERi}).

The second step is to calculate the sum of the individual IERi is as per below equation:

$$I_{ERi} = \frac{AC_i}{RC_i} - 1 \qquad 6.2$$

$$I_{ER} = \sum_{i=1}^{n} I_{ERi} \qquad 6.3$$

Where:

IERi _ index of environmental risk of the element exceeding limit _ risk concentration

ACi _ analytical concentration of the element

RCi _ limit _risk concentration of the element

IER _ overall index of environmental risk of evaluated sample

6.2 Accumulate Risk Index Analysis

All elements exceeding the MCL were considered in the risk index calculation. The cumulative risk analysis indicates that all wells are characterized as exceeding the limit risk concentrations. This is due to the exceeding of at least one element of the limit risk concentration.

Subsequently, the comprehensive assessment map indicates that almost all wells are characterized as exceeding the limit-risk concentrations. For example, the comprehensive map shows that WED 13 is under a high level of risk but the brake down map for BOD (Figure 57) indicates that the well is secure and classified as no risk.

The comprehensive environmental risk assessment map for groundwater in Tarout Island is presented in Figure 56. In addition to that the individual map was also created for each element. At least one of the individual parameters exceeded the limited risk index in all water samples. As a consequence of that the entire area is under risk to different degrees.

The comprehensive risk assessment map indicates a “hot spot” at the industrial area in the north-west area. This is due to high concentration of lead which exceeded the allowable limit of lead in drinking water. The high content of lead in sample WDU 5 makes the area under the high risk regardless the other elements or parameters. The whole industrial area from the western part towards the center of the city is characterized with high levels of risk. It starts decreasing in the eastern part with an exception in the central and northern parts. The individual risk assessment map is discussed in the following sections.

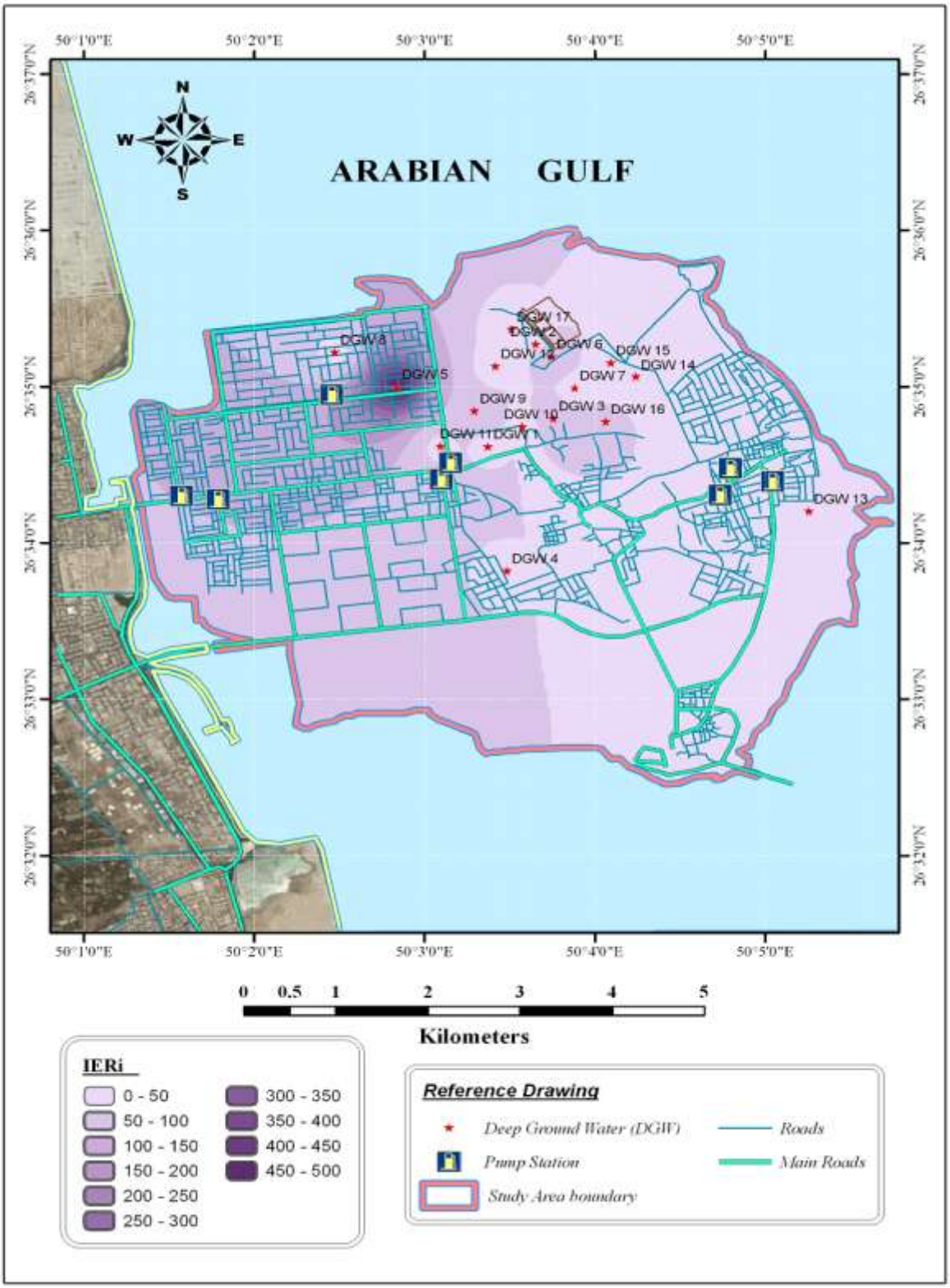


Figure 56: Comprehensive environmental risk level map for groundwater in Tarout Island.

6.3 Individual Risk Index Analysis

The individual risk index results of parameters exceeding the allowable limit are shown in Table 10A in Appendix A.

6.3.1 BOD

As presented in the analytical results, the BOD is high in the central area. Three major hot spots were observed in the central part of the study area. The contaminated wells are mainly located in residential area which explained the high content of BOD. The high risk was detected in 8 wells out of 17. The high concentration of BOD in those wells makes the IER index greater than 1. As a result, these wells are classified as high risk wells. The distribution of risk overall the study area is shown in Figure 57.

If elevated levels of BOD lower the concentration of dissolved oxygen in a water body, there is a potential for profound effects on the water body itself, and the resident aquatic life. When the dissolved oxygen concentration falls below 5 ppm, species intolerant of low oxygen levels become stressed (Khitoliyal et. al., 2009). The lower the oxygen concentration, the greater the stress. Eventually, species sensitive to low dissolved oxygen levels are replaced by species that are more tolerant of adverse conditions, significantly reducing the diversity of aquatic life in a given body of water. If dissolved oxygen levels fall below 2 ppm for more than even a few hours, fish kills can result. At levels below 1 ppm, anaerobic bacteria (which live in habitats devoid of oxygen) replace the aerobic

bacteria. As the anaerobic bacteria break down organic matter, foul-smelling hydrogen sulfide can be produced.

6.3.2 COD

The graphical distribution of COD risk level indicates that the IER is greater than one in the samples collected from wells 3, 6, 9 and 16. The deep water analysis shows that most of the sampled collected from deep ground water exceeded the standard value which is 4 ppm. The medium risk is detected in well number 6 and 3. The remaining samples show no or low risk. This is reflected in the risk map of COD in Figure 58.

6.3.3 Iron

The graphical distribution of iron risk level indicates that the I_{ER} is greater than one in the samples collected from wells 1, 5, 7,9,10, 11, 14 and 16. The deep ground water analysis shows also that the remaining wells are ranged between 0.5 and 1. As a result of that, the area is classified as medium risk in the central area and low risk in most of the remaining area. Refer to environmental risk map Figure 59.

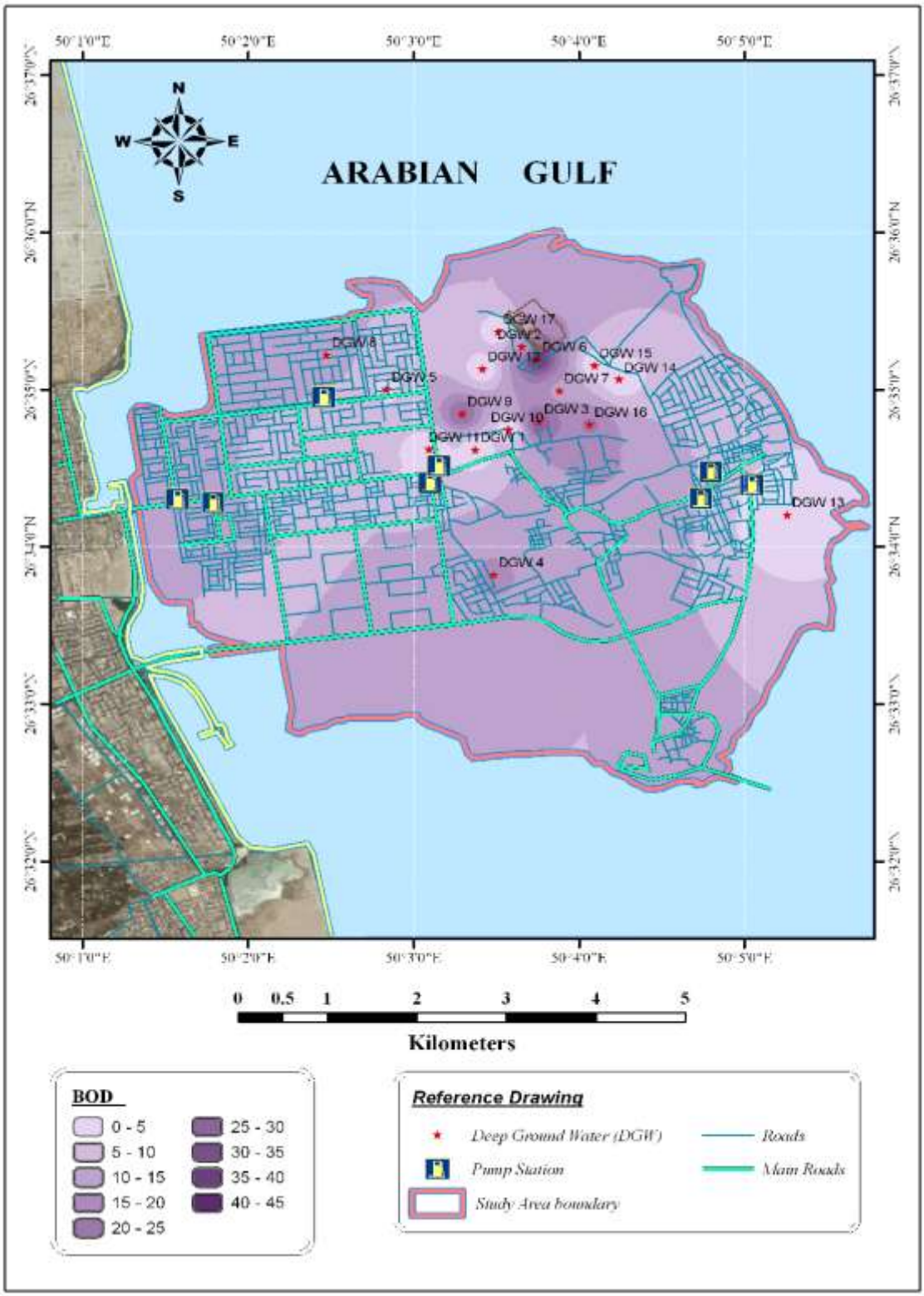


Figure 57: Environmental risk level distributions for BOD

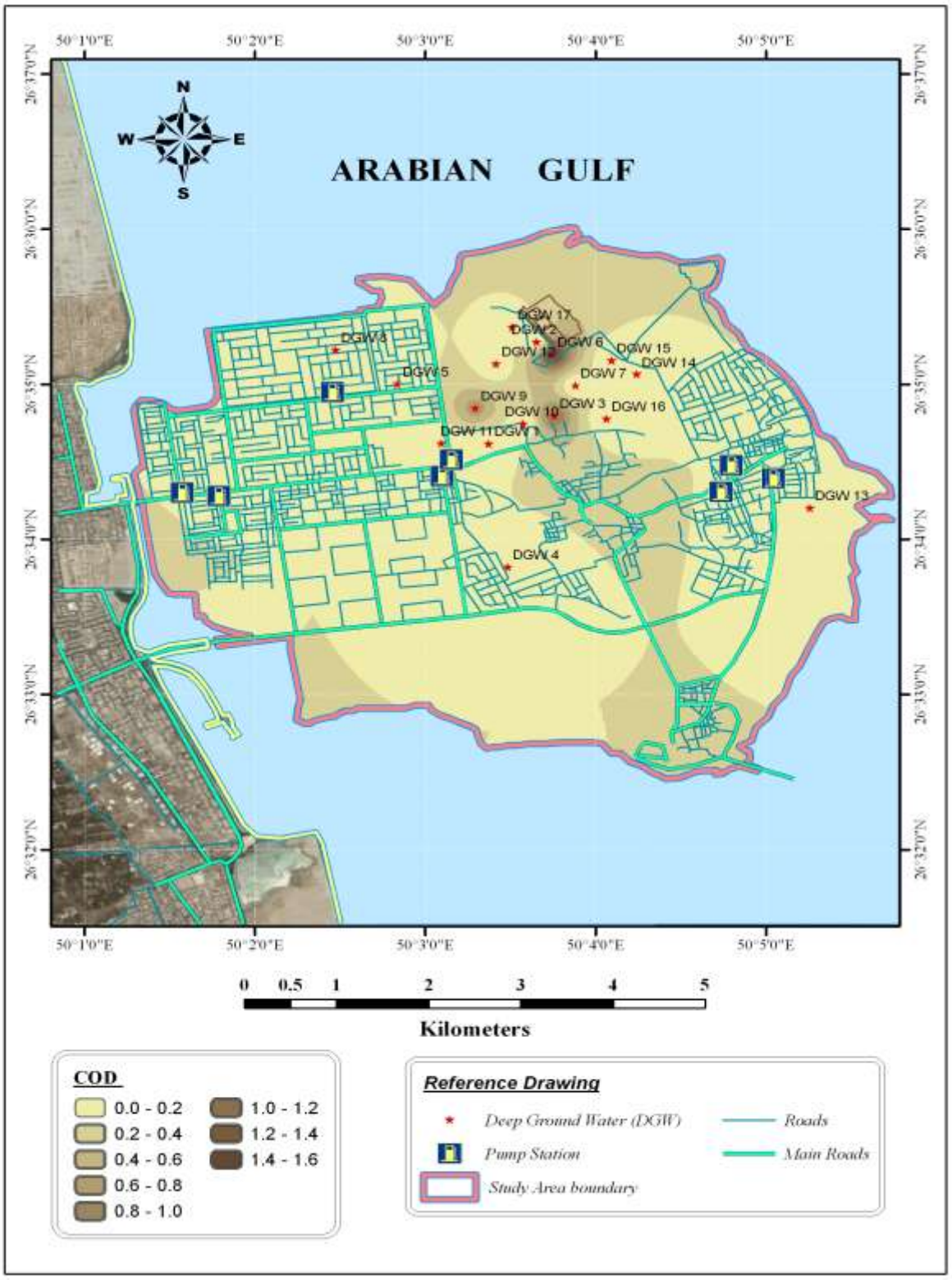


Figure 58: Environmental risk level distributions for COD

6.3.4 Lead

Lead can cause a variety of neurological disorders. In children, it inhibits brain cell development. Lead also prevents the uptake of iron, so people ingesting lead often exhibit symptoms of anemia including pale skin, fatigue, irritability, and mild headaches.

As discussed in the water analysis, the lead content in all wells are within the allowable limit except in sample number 5 in which the lead content exceeded the allowable limit. As a result, the risk index in that particular well exceeded 5 and classified as high risk area. The environmental risk index map (Figure 60) shows that the industrial area in the northwestern part is under risk of lead.

6.3.5 Nitrate

Nitrate is a concern in drinking water because an increased level of nitrate has been linked with blue-baby syndrome in infants. As we mentioned before the nitrate level in the majority of the samples collected from deep aquifer wells were above the MCL of 10 ppm. The highest content of nitrate was found around 43 ppm in well number 7. The nitrate content in wells (6, 8, and 15) were found below the MCL. However they are very close to the MCL value. As a result the risk index analysis shows that samples collected from wells 1, 6, 9 and 10 are classified as medium risk since the I_{ER} is above 1. The risk index classification of wells is presented in Figure 61.

6.3.6 Nitrite

As indicated in the analysis of samples collected from a deep aquifer, three of the wells are contaminated with nitrite which are wells no 2, 6, and 17. This was reflected in the risk index map (Figure 62). The risk level index was above 5 which is classified as very high risk in sample number 2 and 6.

6.3.7 Sulfate

The risk index of sulfate in the deep groundwater exceeded one in most of the wells. It reaches 5 in sample 6. This is due to the high concentrations of sulfate in water. The average concentration of sulfate in the analyzed groundwater samples in the study area in deep groundwater wells was 761 ppm. The maximum value was 1494 ppm in well 7 and the minimum sulfate was found in well 12. As per the numerical indexing of risk level samples 1, 3, 9,16 are classified as high risk and sample 6 is very high risk. They are mainly located in the old city of Tarout in the central part of the study area. The environmental index map shows three zones with high level of risk (Figure 63).

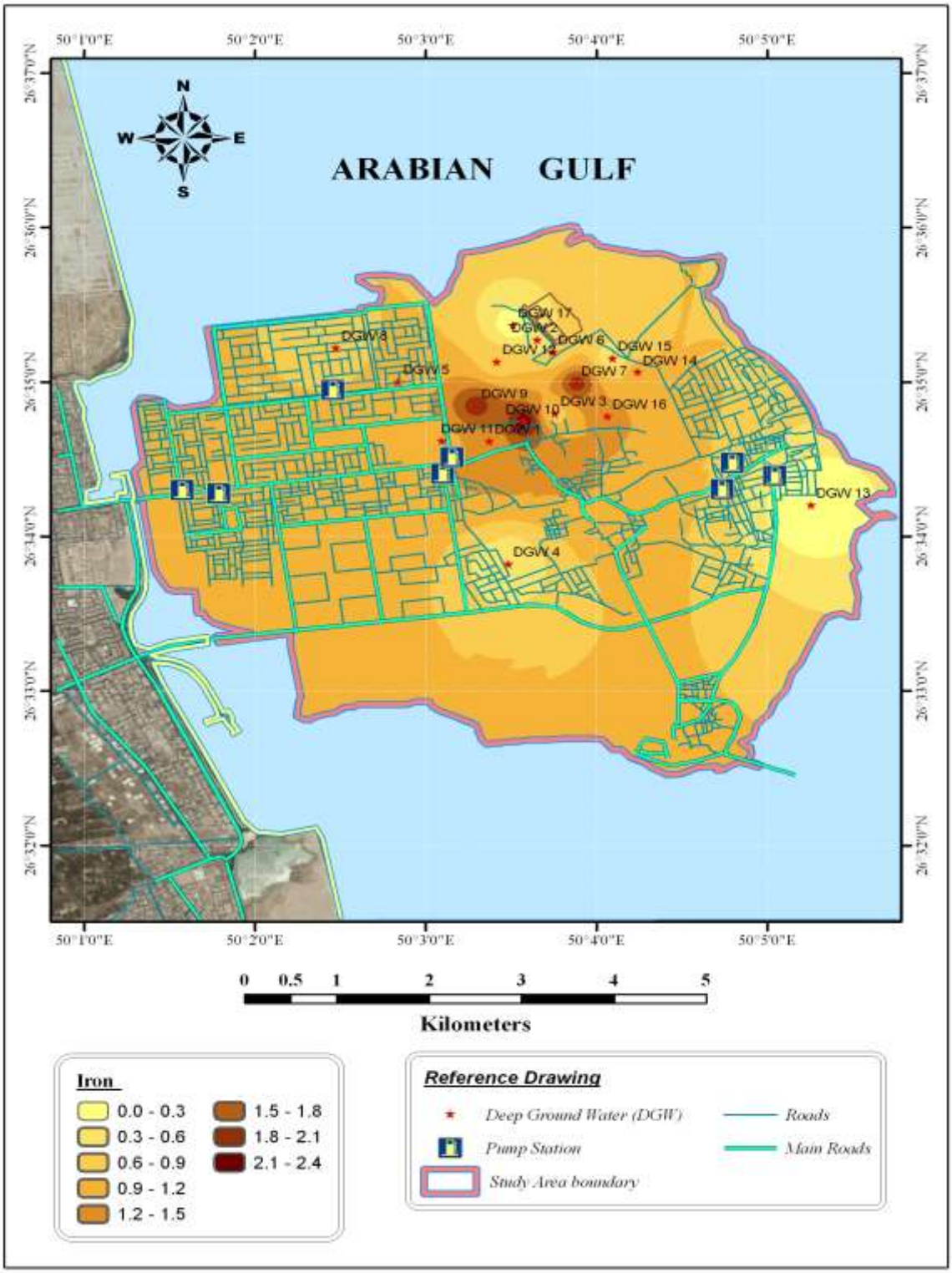


Figure 59: Environmental risk level distribution map for Iron in groundwater

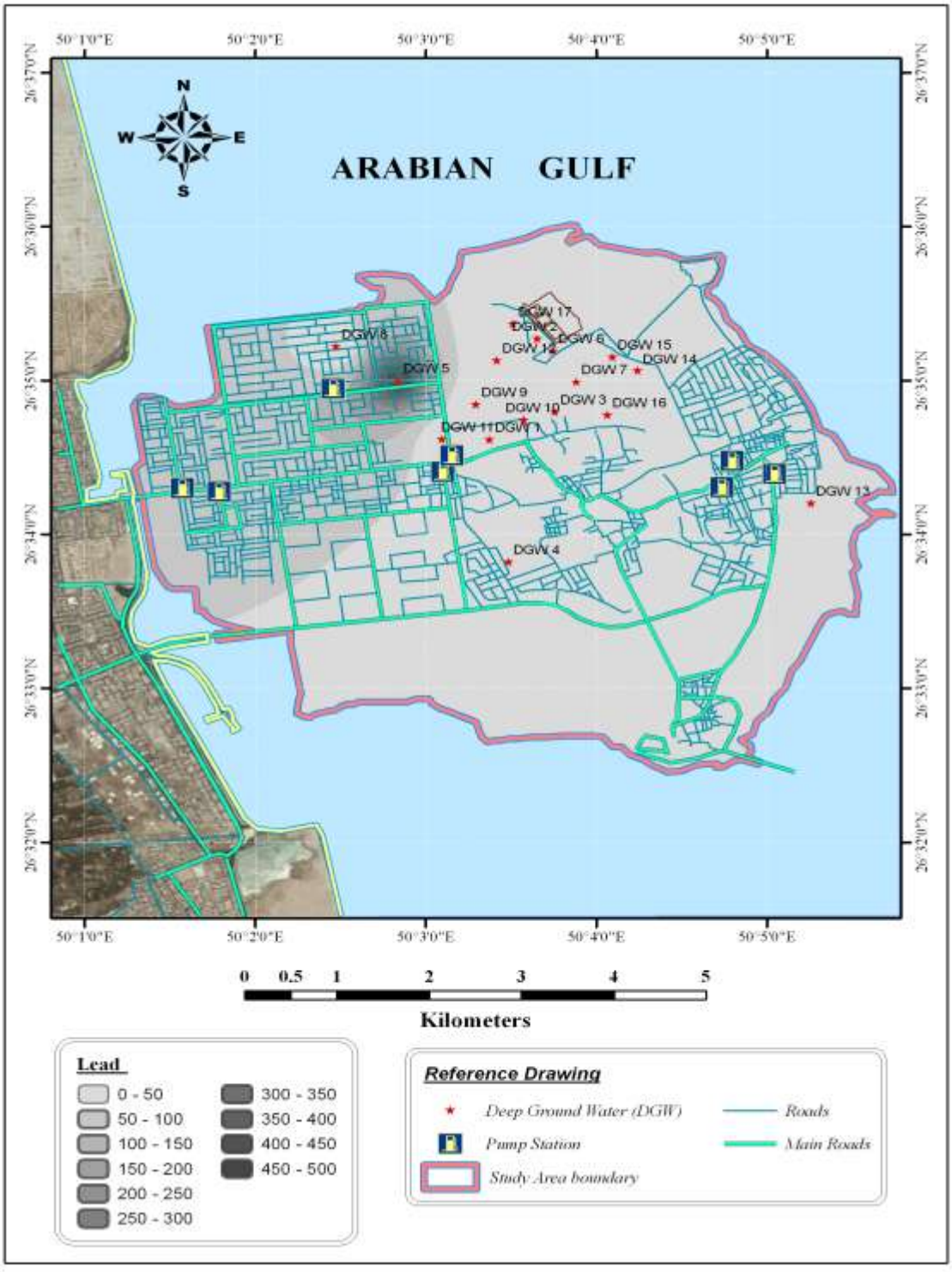


Figure 60: Environmental risk distribution map for lead in groundwater

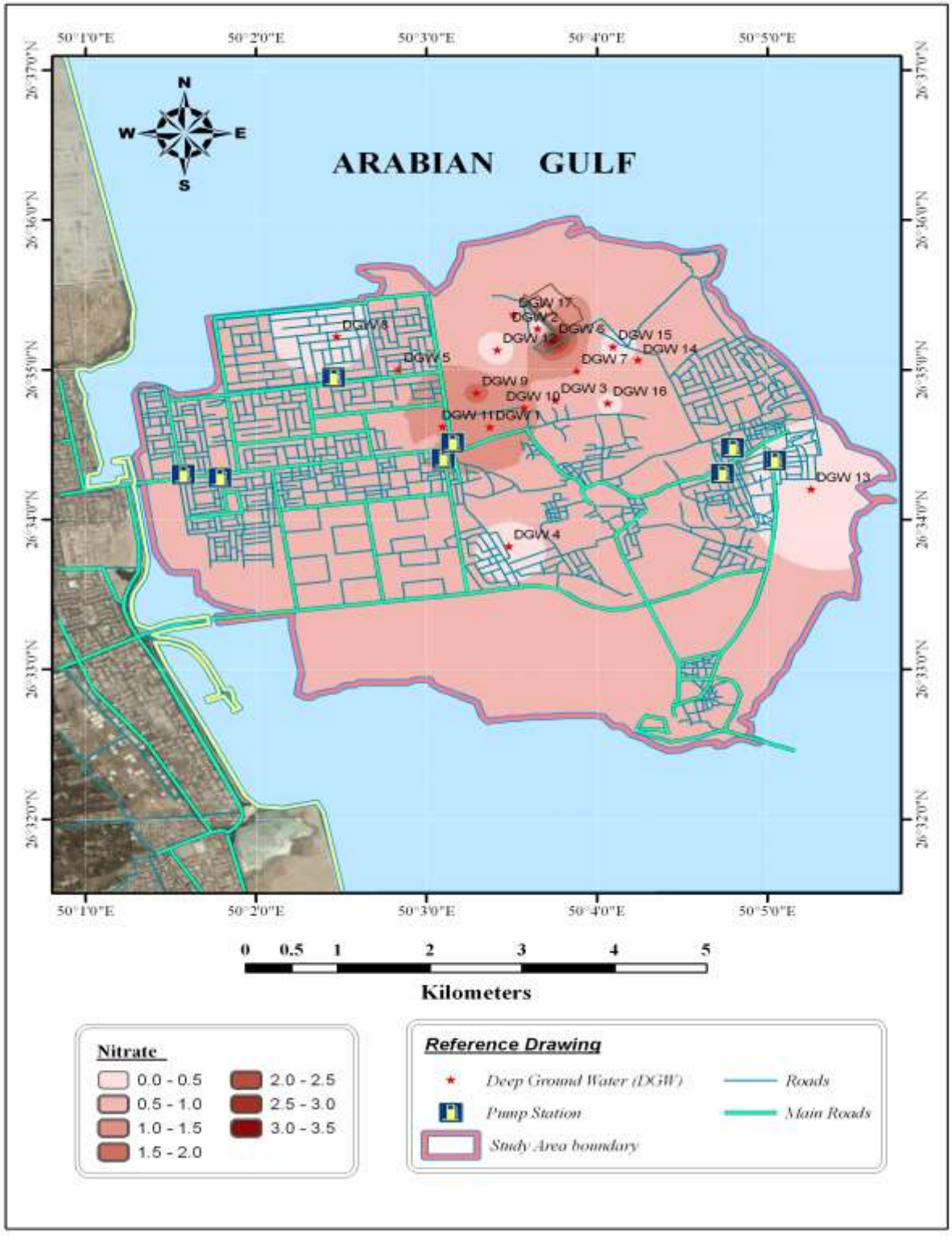


Figure 61: Environmental risk distribution map for nitrate in groundwater

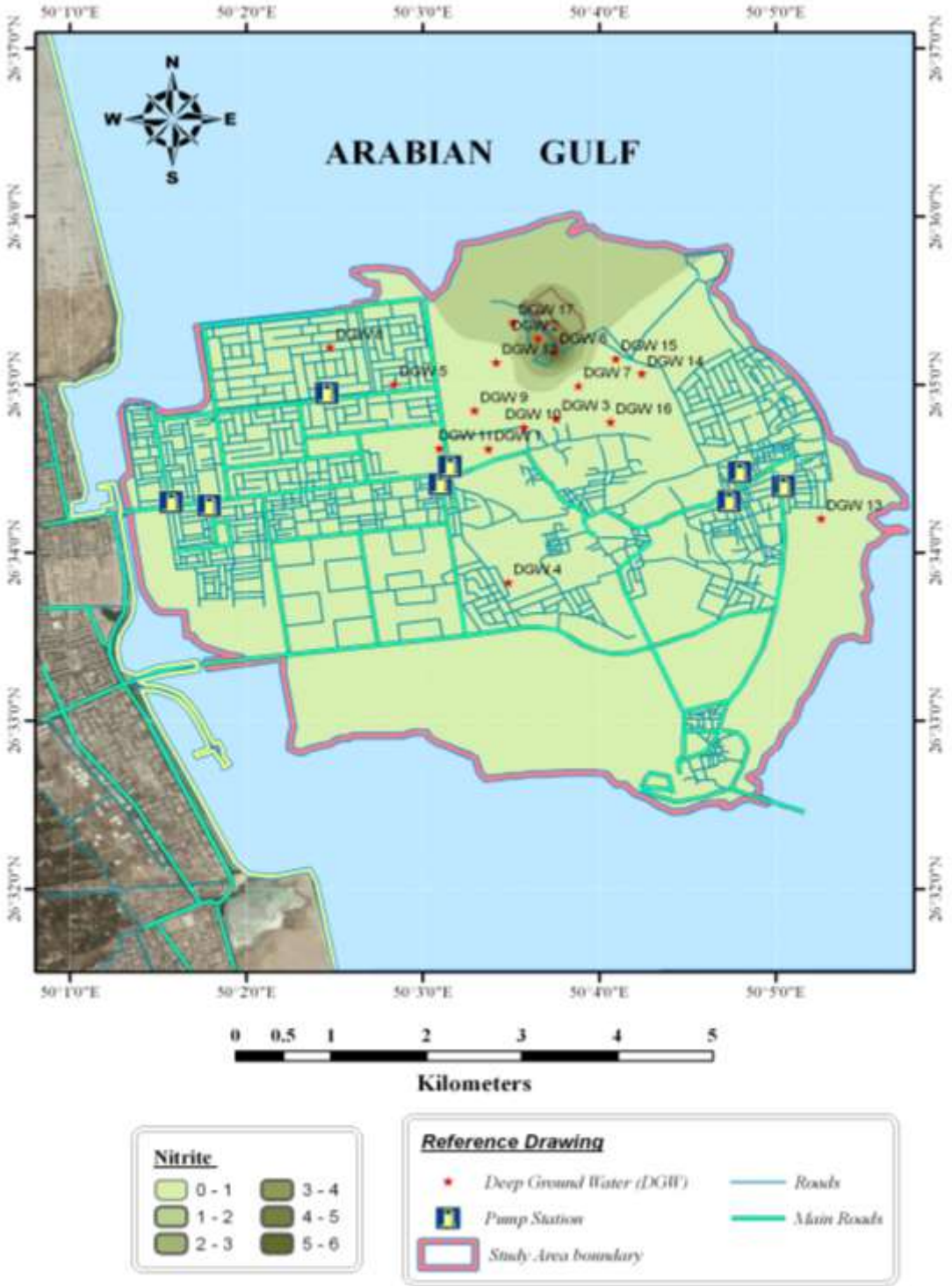


Figure 62: Environmental risk distribution map for nitrite in groundwater

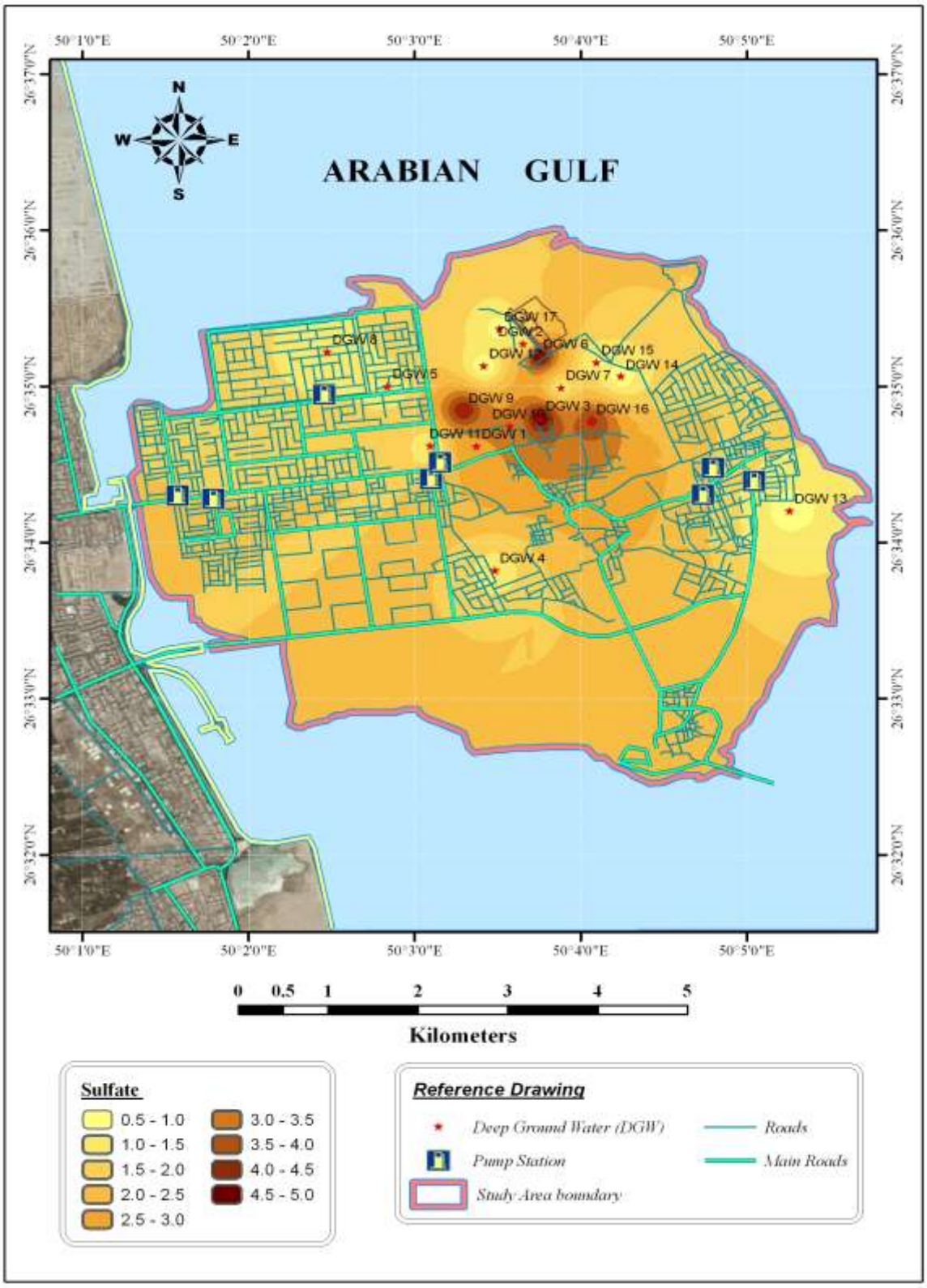


Figure 63: Environmental risk distribution map for sulfate in groundwate

CHAPTER 7

CONCLUSIONS AND RECOMMENDATIONS

7.1 Conclusions

The overall scope of this study was to assess the groundwater quality of Tarout Island in relation to various contamination sources and land uses associated with different industrial and residential activities. Site investigation leads to identify the contamination sources that have direct effect on the deterioration of groundwater quality. The study identified three main sources influencing the groundwater quality:

1. Municipal wastes, septic tanks and storage tanks
2. Waste disposal (solid and liquid waste)
3. Agricultural activities

Water Samples were collected from surface water, shallow ground water, and deep groundwater to study contaminant indicators for each contamination source. Samples collected from surface water are characterized by high concentrations of Ti, Be, Al, Cr, Fe, Cu, As, and Pb. In addition, high concentrations of phenol, benzene, toluene and

styrene were detected. This was attributed to dumping a variety of solid wastes, liquids, paints, and oil products in the area.

Shallow groundwater analysis identified that the shallow water is highly affected by different types of contamination sources such as the agricultural, industrial and municipal sources. The affect of underground or aboveground disposal practices of domestic, municipal, or industrial liquid waste was noticeable in the samples analysis. Septic tank and sewage system influence was highlighted in most of study area. High concentration of phosphate which is considered as one of major fertilizer contamination indicator is detected in all samples collected from shallow groundwater. The contribution of industrial activities and waste disposal practices were identified in some of the samples collected from shallow groundwater. The analysis measured high content of trace metal such as cupper, arsenic and lead.

Underground storage tanks is one of the major source of contamination to the shallow groundwater and one of the expected contamination source to the deep groundwater. BTEX compounds were identified in three out of eleven samples especially those samples located near the underground gasoline tank.

Some of the deep groundwater wells have been contaminated with BOD, COD, Nitrate and Nitrite. This may be attributed to transport of contaminated shallow groundwater to the deep aquifer due bad well-casing and fissures in the upper confining layer of Khobar aquifer.

Conclusions drawn from the current study indicate that the groundwater quality of Tarout Island is not suitable for drinking purposes. This study can be considered as a baseline for any further study in the future.

7.2 Recommendations

1. The poor quality of the shallow ground water emphasizes the need for having ground water quality monitoring programs to trace and detect deep groundwater contamination.

2. The sites should be fully assessed and monitored for the waste disposal.

3. No permission to be issued for any new housing projects not having sewage system.

4. Investigation is required to study the bromide content in groundwater in Tarout Island and the formation of bromate under an ozonoation process.

5. An in-depth study of geology of the ground aquifers in the study area is required to identify the reasons for the contaminant levels of confined aquifer.

6. The unmonitored wells such as private wells in Tarout Island should be closed to prevent any possibility of future contamination of deep groundwater as a result of poor construction and misuse.

7. Monitoring wells should be installed in most of the areas to measure and track the quality of groundwater not only to the deep aquifer but also to the shallow surface.

8. The possibility of providing Tarout Island with water from different sources should be considered to conserve the groundwater resources.

9. To conduct a modeling study of the aquifers and predicting water quality and quantity for at least the next 20 years.

10. Comprehensive hydrogeological investigations must be carried out on local scale before starting any development of pumping projects in the area. This will insure a good management of groundwater.

REFERENCES

1. Abdelmomen, A.E., El-Meleigi, M.A., and Al-Rokaibah, A. A., Chemical Characteristics and Bacterial Contamination of Groundwater in Buraydah, Saudi Arabia, J, King Saud Univ., Vol.2, Agric. Sci. (2), pp-279-290 (1410/1990)

2. Abderrahman, W. A, M. Rasheeduddin, I.M. Al-Harazin, J. M. Esuflebbe, B.S. Eqnaibi, "Imapcts of Management practices on groundwater conditions in Eastern Province, Saudi Arabia", Hydrogeology Journal, Vol.3 No.4, 1995

3. Abderrahman. W.A., 1990, The effects of groundwater use on the chemistry of spring water in Al-Hassa Oasis: Journal of King Abdulaziz University, Earth Science, v. 3, Special issue: First Saudi Symposium on Earth Science, Jeddah, 1989, p.259-265

4. Agency for Toxic Substances and Disease Registry (ATSDR). 2004. Toxicological Profile for Copper. Atlanta, GA: U.S. Department of Health and Human Services, Public Health Service.

5. Alhajjar, B.J., Chesters, G., and Harkin, J. M., 1990 Indicators of Chemical Pollution from septic system, Groundwater, vol. 28, No. 4, pp. 559-568

6. Ahn H-I, Chon H-T (1999) Assessment of groundwater contamination using geographic information systems. Environ Geochem Health 21:273–289

7. Al-Tamimi, M. H., 1985, stratigraphical and microfiches analysis of Early Paleogene succession in Dammam dome, Eastern Saudi Arabia: M.Sc. thesis, king Fahad University of Petroleum and Minerals, Dhahran, Saudi Arabia, 92 p.

8. Al-Sayyari, S. S., and Zottle, J. G., 1978, Quaternary Period in Saudi Arabia, vol. 2, springer-verlag, wein, New York.

9. Alyaum news paper, www.alyaum.com, 2007

10. Anon (1994a) Commission regulation (EC) No. 1488/94 of 28 une 1994 laying down the principles for the assessment of risks to man and the environment of existing substances in accordance with Council regulation (EEC) No. 793/93 (Text with EEA relevance). Official journal No L (161), 29 June 1994:0003-0011

11. Anon (1998a) Methodological directive of 22 October 1998 No. 623/98-2 of the Slovak Environmental Ministry concerning guidelines for risk assessment and management. In: Standpoints, reports and information of MZˇP SR, pp 51–71

12. Backiewicz, W., D. M. milne, and M. Noori (1982). Hydrogeology of Umm Er r*adhuma aquifer*. *Saudi Arabia, with reference to fossil gradients, Quarterly*. Journal of Engineering Geology. Vol. 15, pp. 105-126

13. Bohlke, J. K. and J. M. Denver. “Combined Use of Groundwater Dating, Chemical, and Isotopic Analyses to Resolve the History and Fate of Nitrate Contamination in Two Agricultural Watersheds, Atlantic Coastal Plain, Maryland, “Water Resour. Res., 31(9):2319-2339 (1995).

14. Bureau De Recharge Geologiques et Mineres (BRGM). Al-Hassa Development Project: Groundwater Resources Study and Management Program: Unpublished report to Ministry of Agriculture and Water, Riyadh, Saudi Arabia, 4 Vols.

15. Carter, T.A and Sneed, R.E., 2001 Drinking Water Quality for Poultry, Publication number-PS&T # 42, North Carolina Cooperative Extension Service.

16. Central Department of Statistics & information, 2004

17. David H.F.Liu, Bela G.Liptak., 2000. Groundwater and surface water pollution.

18. Domenico, P. A., Franklin and W. Schwartz., “Physical and chemical hydrogeology”, 2nd ed.

19. Douglas, I. 1983. The Urban Environment. Edward Arnold: Baltimore, MD.

20. Dufor C.N., and Becker, E., 1964, Puplic water supplies of the 100 largest cities in the United States, 1962: U.S Geological Survey, water supply paper 1812

21. Elhatip H, Afsin M, Kuscu I, Dirik K, Kurmac Y, Kavurmaci M (2003) Influence of human activities and agricultural on groundwater quality of Kayseri-Incesu-Dokuzpinar springs, central Anatolian part of Turkey. Environ Geol 44:490–494

22. Fetter, C.W. (2001), Applied Hydrogeology, Prentice-Hall, New Yourk, USA, 4th ED: 598 p.

23. Flips, W.J., Katz, B.G., Linder, J.B. and Markel, R., 1984 Sources of Nitrate in Groundwater in sewered Housing Development, Central Long Island, New Yourk, Ground water, Vol.22, No. 4, pp418-426

24. Foster, S.S. and Lawrence, A.R. (1996), An international perspective of urban groundwater -from anarchy towards sustainability, In C Barber & G Davis, (Ed's), Proc. Groundwater & Lande-Use Planning, Centre for Groundwater Studies, Fremantle,WA, September 1996, 1-11.

25. Groundwater Development Consultants (GDC), 1980, Umm er Radhuma Study: Demeter House, Station Road, Cambridge, CBI 2RS: Unpublished report of Agriculture and Water, Riyadh, Saudi Arabia.

26. Hassan, H, M,. 1992, Hydrogeology of Alat and Khobar aquifers in eastern Saudi Arabia: King Fahd University of Petroleum and Minerals, Dhahran, Saudi Arabia, M.S. thesis, 156 p.l Survey Water-Supply Paper 2254, 264 pp.(1985).

27. Health Canada, Guidelines for Canadian Drinking Water Quality Supporting Documents.http://www.hc-sc.gc.ca/ewh-semt/pubs/water-eau/doc_sup-appui/index_e.html, 2010.

28. Hem, J. D. Study and Interpretation of the Chemical Characteristics of Natural Water. 3rd edition, U>S. Geological Survey Water-Supply Paper 2254, 264 pp. (1985)

29. Heam, J. O., 1989 Study and interpretation of the chemical characteristics of natural water, (3rd ed.), USGS WSP 2254, Washington, D.C pp 263.

30. Huang W, Tasi Y, Chu C., 2003, Evaluation of Disinfection By-products Formation During Ozonation of Bromide-Containing Groundwater , Journal of Environmental Science and Health, Part A, Volume 38, Issue 12 December 2003 , pages 2919 - 2931

31. Ibe Sr, K.M. and Agbamu, Pat U., 1997, Impacts of human activities on groundwater quality of an alluvial aquifer: a case study of the Warri River, Delta State, SW, Nigeria, International Journal of Environmental Health Research, 9:4, 329-334.

32. Ishaq A. M., M. S. Al-Suwaiyan, A. A. Al-Sinan, "Suitability of Wastewater Effluents to Recharge Groundwater Aquifers in Saudi Arabia", International Symposium on Artificial Recharge of Groundwater, 1995.

33. Italconsult, “Water and Agricultural Development Studies for Area IV, Eastern Province, Saudi Arabia”, Unpublished report to Ministry of Agriculture and Water, Riyadh, Saudi Arabia, 1969.

34. Jiao, J.J, 2000, Modification of regional groundwater regimes by land reclamation, Hong Kong Geologist, Vol 6, p29-36.

35. Johnson, C., 1978, hydrochemical Investigations in the Areas of AlQatif and Al Hassa, Quatenary Period in Saudi Arabia, vol.1, springer-Verlag, Wien, New Yourk, pp. 93-119

36. Lerner, 1986. Leaking pipes recharge groundwater. Ground Water, 24(5), 654-662.

37. Lerner, D. N., Issar, A. S. & Simmers, I. 1990. Groundwater recharge. A guide to understanding and estimating natural recharge, Heinz Heise, International Contributions to Hydrogeology, 8.

38. Lerner, D.N. (2002) Identifying and quantifying urban recharge: areview. Hydrogeol. J. 10, 143–152.

39. Mahmood, H. R. & Twigg, D. R.(1995). Statistical analysis of water table variations in Bahrain, *Quarterly Journal of Engineering Geology and Hydrogeology*; 1995; v. 28; issue.Supplement_1; p. S63-S74.

40. Mangore, E. and Taigbenu, AE, 2004. Land use impacts on the quality of groundwater in Bulawayo, ISSN 0378-4738 SA Vol.30 No. 4 October 2004.

41. Mathhes, G., 1982 The properties of Groundwater, John Wily & Sons, New York. 397p

42. Melian R, Myrlian N, Gouriev A, Moraru C, Radstake F (1999), Groundwater quality and rural drinking-water supplies in the Republic of Moldova. Hydrogeol J 7:188–196

43. Ministry of Agriculture and Water (MAW), "Water Atlas of Saudi Arabia," 1986.

44. Morris, B.L. et al. (2003), Groundwater and its susceptibility to degradation : a global assessment of the problem and options for management, Early Warning and Assessment Report Series, United Nations Environment Programme, Nairobi, Kenya, Report RS 03-3: 162 p.

45. Mudd, G.M.; Deletic, A. ; Fletcher T.D. and A. Wendelborn (2004) , A Review of Urban Groundwater in Melbourne : Considerations forWSUD. Institute for Sustainable Water Resources,Department of Civil EngineeringMonash University, Clayton, VIC 3800 AUSTRALIA

46. National Academy of Sciences. Drinking Water and Health.(National Research Council) Nat. Acad. of Sci., Washington, D.C. (1977).

47. Power, J. F.; Schepers, J. S. 1989: Nitrate contamination of groundwater in North America. Agriculture ecosystems and environment 26: 165—187.

48. Presidency of Meteorology and Environment (PME), Saudi Arabia, 2009, www.pme.gov.sa

49. Ramis S, "Tarout Island", Salman Ramis, Second Addition, 2006.

50. Rasheeduddin, M., 1988. Numerical Modeling of Alat, Khobar and Umm Er Radhuma aquifer Systems in Eastern Saudi Arabia, M.S. thesis KFUPM Dhahran, Saudi Arabia.

51. Rasheeduddin, M., 1999. A Groundwater Resources Development Study Of A Regional arid Zone Multi-Aquifer System: Eastern Province, Saudi Arabia: Birmingham University, UK. P.H.D. thesis, 80 p.

52. Khitoliyal R.K., S. Arora and S, Jaitley., 2009. Groundwater Contamination By Municipal Solid Waste Landfill: a Case Study, Proceedings of International Conference on Energy and environment.

53. Salt Water Intrusion Conference 1st SWIM SWICA First International Joint,: www.sciencedaily.com/releases/2007/07/070727091903.htm

54. SEAWATER INTRUSION TOPIC PAPER (Final) Approved by WRAC: 2/3/05, Approved by BOCC 3/16/05 Island County / WRIA 6 Watershed Planning Process

55. Schwartz, F.W., and Zhang,H. (2003), Fundamentals of Ground water.

56. Sikora, L. J. and Keeney, D. R. laboratory studies on stimulation of biological denitrification. P. 64-74. In:Proc. Symp. Home. Sewage Disposal Publ. 175. Am. Soc. Agric. Eng, St. Joseph, Mich. 242P, 1975.

57. Singh KP, Malik A, Mohan D, Singh VK, Sinha S (2006), Evaluation of groundwater quality in northern Indo-Gangetic alluvium region. Environ Monitor Assess 112:211–230

58. Taha, A.A, El-Mahmoudi, A.S and El-Haddad, I.M. (2004), Pollution Sources and related Environmental Impacts in the New Communities Southeast Nile Delta, Egypt, Emirates Journal for Engineering Research, 9(1), 35-49.

59. United Nations (1982). Groundwater in the Eastern Mediterranean and Western Asia, Natural Resources/Water Series No. 9, p.229

60. U.S. Army Center for Health Promotion & Preventiv Medicine, 2009 http://chppm-www.apgea.army.mil, http://usachppm1.army.smil.

61. Umar R, Ahmad MS (2000) Groundwater quality in parts of central Ganga Basin, India. Environ Geol (Cases and Solutions) 39(6)

62. U.S. Environmental Protection Agency. "Quality Criteria for Water," prepublication copy (1976a).

63. U.S. Environmental Protection Agency 1983. Hazardous waste land treatment. SW-874. Washington, D.C.: U.S. EPA, Office of Solid Waste and Emergency Response.

64. U.S. EPA National Primary drinking water standards-2004

65. US EPA Region 1. Groundwater Sampling, Revision 0. January 9, 2003.

66. Valcav and Valcav, 1992 S. Valcav and V. Valcav, Lubricants and Special Fluids, Elsevier, Amsterdam (1992).

67. Water & Sewage Authority of the Eastern Province, preliminary study reports volume 2 of 2.

68. B.C.'s Ground Water Protection Regulation , WATER STEWARDSHIP INFORMATION SERIES (2007), http://www.env.gov.bc.ca/wsd/plan_protect_sustain/groundwater/library/ground_fact_sheets/pdfs/na(020715)_fin2.pdf

69. William J. Deutsch (1997), Groundwater Geochemistry: Fundamentals and applications to contamination.

70. William M. Flanagan (1998), Dissolved Lithium Concentrations, Gender, Race, and the Geography of Texas Suicide Mortality Rates 1980–1998: A Correlation Study. Department of Geography, College of Arts and Sciences

71. Yates, M.V. and Yates, S.R., 1993 Pathogens in W.M. alley (editor), Regional Groundwater Quality, Van Nostrand Reinhold, New Yoirk, pp383-404.

APPENDIX A

CHEMICAL ANALYSIS RESULTS

APPENDIX A
CHEMICAL ANALYSIS RESULTS

Surface Water Analysis

Table A-1: Heavy Metal analysis of samples collected from surface water

Well #	Unit	SW 1	SW 2	SW 3	Average	EPA
Ti	ppm	1.9	1.7	2.2	1.93	NA
Be	ppm	0.01	0.25	0.37	0.21	0.004
Al	ppm	0.05	0.31	0.09	0.15	0.05
Sr	ppm	4.4	5.9	4.2	4.83	NA
Cr	ppm	0.15	0.84	0.49	0.49	0.1
Fe	ppm	1.1	1.2	0.62	0.97	0.3
Cu	ppm	1.47	2.15	0.85	1.49	1.3
As	ppm	0.02	0.03	0.02	0.02	0.01
Cd	ppm	0.001	0.001	0.002	0.00	0.005
Ba	ppm	0.02	0.04	0.03	0.03	2
Pb	ppm	0.09	0.04	0.07	0.07	0.015

Table A-2: Hydrocarbon analysis of samples collected from surface water

Parameters	Unit	SW 1	SW 2	SW 3	EPA
Phenol	ppm	1.5	0.87	0.09	NA
Benzen	ppm	0.14	1.47	0.85	0.005
Toluene	ppm	0.98	1.9	0.79	1
EDC	ppm	ND	ND	ND	NA
ETH Benzene	ppm	0.45	2.1	1.1	0.7
Styrene	ppm	0.24	1.78	0.17	0.1
MTBE	ppm	ND	1.52	0.08	NA
O-Xylene	ppm	0.01	0.85	0.46	NA

Shallow Ground Water Analysis

Table A-3: Anion & Cations analysis of samples collected from shallow ground water

Sample No	Fluoride	Chloride	Nitrite	Bromide (Br^-)	Nitrate (NO_3^-)	Phosphate (PO_4^{3-})	Sulfate (SO_4^{2-})
Unit	ppm	ppm	ppm	ppm	ppm	ppm	ppm
SGW 1	1.08	1510	10.5	5.33	2.7	4821	2152
SGW 2	0.47	5887	7.4	14.7	5322	3278	6875
SGW 3	1.57	2109	15.7	6.04	38.44	4526	2190
SGW 4	0.54	3265	ND	25.94	21.61	6030	2543
SGW 5	1.42	3674	1.49	29.57	13.34	4827	2591
SGW 6	0.87	5483	ND	1.86	14	3471	7425
SGW 7	0.47	4871	8.71	5.71	14.25	1498	5482
SGW 8	0.29	5247	15.89	1.81	25.81	5479	3816
SGW 9	0.35	4518	31.58	ND	8.47	3729	5297
SGW10	0.19	4618	201	10.78	49	4167	3864
SGW11	0.48	4781	187	9.46	38	5329	5421

Table A-4 : Heavy Metal analysis of samples collected from shallow groundwater

PARAMETAR	Unit	Agriculture & Residential area			Industrial & Residential area			Agriculture Area					Average
		SGW 1	SGW 2	SGW 3	SGW 4	SGW 5	SGW 6	SGW 7	SGW 8	SGW 9	SGW 10	SGW 11	
Lithium	ppm	0.156	0.289	0.07	0.14	0.18	0.21	ND	ND	ND	ND	ND	0.17
Beryllium	ppm	ND	ND	ND	0.02	0.008	0.008	ND	ND	ND	ND	ND	0.01
Aluminum	ppm	ND	ND	ND	8	ND	3	ND	ND	ND	ND	ND	5.50
Vanadium	ppm	0.024	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	0.02
Chromium	ppm	ND	0.001	ND	ND	1	2	ND	ND	ND	ND	ND	1.00
Manganese	ppm	0.03	ND	ND	ND	2.5	ND	0.005	0.003	0.01	0.03	0.01	1.73
Iron	ppm	0.17	0.308	0.08	0.18	0.216	0.358	0.12	0.06	0.078	0.045	0.58	0.20
Cobalt	ppm	0.008	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	0.01
Nickel	ppm	ND	ND	ND	0.002	ND	ND	ND	ND	ND	ND	ND	0.00
Cupper	ppm	ND	ND	ND	1	2	1	ND	ND	ND	ND	ND	1.33
Zinc	ppm	ND	ND	ND	ND	ND	ND	ND	ND	ND	0.01	0.006	0.01
Arsenic	ppm	ND	ND	ND	ND	0.03	ND	ND	ND	ND	ND	ND	0.03
Selenium	ppm	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Lead	ppm	ND	ND	ND	0.03	0.02	ND	ND	ND	ND	ND	ND	0.03
Molybdenum	ppm	0.03	0.06	ND	0.05	0.02	0.03	ND	ND	ND	ND	ND	0.04
Palladium	ppm	0.007	0.008	0.004	0.006	0.005	0.002	ND	ND	ND	ND	ND	0.01

Table A-5 : Hydrocarbon Analysis of water samples collected from Shallow Groundwater

PARAMETAR	Unit	Agriculture & Residential area			Industrial & Residential area			Agriculture Area					Average
		SGW 1	SGW 2	SGW 3	SGW 4	SGW 5	SGW 6	SGW 7	SGW 8	SGW 9	SGW 10	SGW 11	
Phenol	ppm	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Benzen	ppm	ND	1.6	ND	ND	0.9	ND	ND	ND	2.7	ND	ND	1.73
Toluene	ppm	ND	1.9	ND	ND	0.6	ND	ND	ND	ND	ND	ND	1.25
EDC	ppm	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
ETH Benzene	ppm	ND	ND	ND	ND	1.8	ND	ND	ND	ND	ND	ND	1.80
Styrene	ppm	ND	2.1	ND	ND	1.3	ND	ND	ND	ND	ND	ND	1.70
MTBE	ppm	ND	1.7	ND	ND	2.5	ND	ND	ND	1.8	ND	ND	2.00
O-Xylene	ppm	ND	1.0	ND	ND	1.2	ND	ND	ND	ND	ND	ND	1.10

Table A-6: Anions and Cations Analysis of samples collected from deep groundwater

PARAMETAR	Unit	DGW 1	DGW 2	DGW 3	DGW 4	DGW 5	DGW 6	DGW 7	DGW 8	DGW 9	DGW 10	DGW 11	DGW 12	DGW 13	DGW 14	DGW 15	DGW 16	DGW 17
F^-	ppm	ND	ND	0.81	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Cl^-	ppm	2961	1891	3218	1982	1807	3919	2014	2003	3588	2941	184	1355	1696	1481	1882	3460	1114
NO_2^-	ppm	0.01	5	ND	ND	ND	6.5	0.12	ND	0.03	ND	ND	ND	0.25	ND	ND	ND	2.5
Br^-	ppm	6.8	6.2	5.9	7.5	4.1	10.3	6.6	4.1	10.1	8.5	4.9	4	6.4	6	6.4	9.3	4.5
NO_3^-	ppm	20.9	12.3	16.5	13	7.5	43.4	7.2	10	27.3	20.8	8.4	9.6	12.3	15.4	12.1	14	14.7
PO_4^{2-}	ppm	ND	20	ND	ND	ND	17	ND	ND	0.12	ND	ND	ND	ND	ND	ND	ND	29
SO_4^{2-}	ppm	1000	517	1452	567	527	1494	547	515	1346	991	492	395	464	432	476	1283	431
Li^+	ppm	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Na^{2+}	ppm	1018	665	1179	713	659	1313	728	706	1214	1002	681	507	610	552	653	1166	443
NH_4^+	ppm	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
K^+	ppm	56.7	36.6	58.9	40.4	36.9	69.1	41.3	41.1	66.3	52.6	39.8	28.3	35.5	32.8	34.6	66.3	28.4
Mg^{2+}	ppm	551	353	687	373	355	691	374	360	661	528	384	272	317	327	332	679	278
Ca^{2+}	ppm	1653	1478	3124	1463	1587	2137	1017	974	2911	1710	1501	814	917	1980	1802	3198	1197

Table A-7: Heavy Metal analysis of samples collected from deep groundwater

Well #	Li ppm	Be ppm	Al ppm	V ppb	Cr ppm	Mn ppm	Fe ppm	Co ppm	Ni ppm	Cu ppm	Zn ppm	As ppm	Sr ppm	Ag ppm	Cd ppm	Ba ppm	Pb ppm
DGW 1	0.03	ND	0.01	0.01	ND	ND	0.7	ND	ND	0.02	ND	0.002	4.6	ND	ND	0.012	ND
DGW 2	0.03	ND	ND	ND	ND	ND	0.4	ND	ND	0.02	ND	ND	2.2	ND	ND	0.014	ND
DGW 3	0.03	ND	ND	2	ND	ND	0.5	ND	ND	0.02	ND	ND	2.6	ND	ND	0.011	ND
DGW 4	0.02	ND	0.01	2	ND	ND	0.4	ND	ND	0.02	ND	ND	2.1	ND	ND	0.02	ND
DGW 5	0.02	ND	0.02	2	ND	ND	0.6	ND	0.01	0.02	0.4	ND	2.3	ND	ND	0.013	0.01
DGW 6	0.03	ND	ND	2	ND	ND	0.5	ND	ND	0.02	ND	ND	2.6	ND	ND	0.02	ND
DGW 7	0.05	ND	0.03	7	ND	ND	0.9	ND	ND	0.03	ND	0.003	5.9	ND	ND	0.012	ND
DGW 8	0.03	0.02	0.01	2	ND	ND	0.5	ND	ND	0.02	0.01	ND	2.7	ND	ND	0.02	ND
DGW 9	0.05	ND	ND	7	ND	ND	0.9	ND	ND	0.03	ND	0.002	4.5	ND	ND	0.011	ND
DGW 10	0.05	ND	ND	7	ND	ND	0.9	ND	ND	0.03	ND	ND	5.6	ND	ND	0.015	ND
DGW 11	0.03	ND	ND	4	ND	ND	0.6	ND	ND	0.02	ND	0.001	3.2	ND	ND	0.011	ND
DGW 12	0.03	ND	ND	2	ND	ND	0.5	ND	ND	0.02	0.01	ND	2.4	ND	ND	0.013	ND
DGW 13	**0.01**	ND	ND	2	ND	ND	0.3	ND	ND	0.01	ND	ND	1.7	ND	ND	0.013	ND
DGW 14	0.03	ND	ND	3	ND	ND	0.6	ND	ND	0.02	ND	ND	3.2	ND	ND	0.012	ND
DGW 15	0.03	ND	ND	2	ND	ND	0.4	ND	ND	0.02	ND	ND	2.2	ND	ND	0.012	ND
DGW 16	0.04	ND	ND	6	ND	ND	0.7	890	ND	0.03	ND	0.002	4.1	ND	ND	0.011	ND
DGW 17	0.02	ND	ND	2	ND	ND	0.4	526	ND	0.02	ND	ND	2.1	ND	ND	0.011	ND

Table A-8: Hydrocarbon analysis of samples collected from deep groundwater

Well #	Phenol ppm	Benzene ppm	Toluene ppm	EDC ppb	ETH Benzene ppm	Styrene ppm	O-Xylene ppm
DGW 1	ND	ND	ND	ND	ND	ND	ND
DGW 2	ND	ND	ND	ND	ND	ND	ND
DGW 3	ND	ND	ND	ND	ND	ND	ND
DGW 4	ND	ND	ND	ND	ND	ND	ND
DGW 5	ND	ND	ND	ND	ND	ND	ND
DGW 6	ND	ND	ND	ND	ND	ND	ND
DGW 7	ND	ND	ND	ND	ND	ND	ND
DGW 8	ND	ND	ND	ND	ND	ND	ND
DGW 9	ND	ND	ND	ND	ND	ND	ND
DGW 10	ND	ND	ND	ND	ND	ND	ND
DGW 11	ND	ND	ND	ND	ND	ND	ND
DGW 12	ND	ND	ND	ND	ND	ND	ND
DGW 13	ND	ND	ND	ND	ND	ND	ND
DGW 14	ND	ND	ND	ND	ND	ND	ND
DGW 15	ND	ND	ND	ND	ND	ND	ND
DGW 16	ND	ND	ND	ND	ND	ND	ND
DGW 17	ND	ND	ND	ND	ND	ND	ND

Environmental risk index calculation

Table A-09 : Environmental risk index calculation of elements exceeding the standard limit of samples collected from deep groundwater

PARAMETERS	Units	Analytical Concentration of the elements exceeding limit																	(I_{ERi})
		DGW 1	DGW 2	DGW 3	DGW 4	DGW 5	DGW 6	DGW 7	DGW 8	DGW 9	DGW 10	DGW 11	DGW 12	DGW 13	DGW 14	DGW 15	DGW 16	DGW 17	
BOD	ppm	0	2.89	5.87	3.1	0.79	8.74	2.71	2.41	5.23	0	0	0	0	0	0	4.17	0	0.2
COD	ppm	0	3.1	7.9	2.79	1.22	10.54	3.41	2.1	6.78	2.11	0	0.31	0	0	1.02	6.54	0	4
Chloride	ppm	2961	1891	3218	1982	1807	3919	2014	2003	3588	2941	184	1355	1696	1481	1882	3460	1114	250
Iron	ppb	0.7	0.4	0.5	0.4	0.6	0.5	0.9	0.5	0.9	1.0	0.6	0.5	0.3	0.6	0.4	0.7	0.3	0.3
Lead	ppb	0	0	0	0	7	0	0	0	0	0	0	0	0	0	0	0	0	0.015
Nitrate	ppm	20.9	12.3	16.5	13	7.5	43.4	7.2	10	27.3	20.8	8.4	9.6	12.3	15.4	12.1	14	14.7	10
Nitrite	ppm	0.01	5	0	0	0	6.5	0.12	0	0.03	0	0	0	0.25	0	0	0	2.5	1
Sodium	ppm	1018	665	1179	713	659	1313	728	706	1214	1002	681	507	610	552	653	1166	443	200
Sulfate	ppm	1000	517	1452	567	527	1494	547	515	1346	991	492	395	464	432	476	1283	431	250

Table A-10 : Cumulative Environmental risk index calculation of elements exceeding the standard limit of samples collected from deep groundwater

Elements	Units	Index of environmental risk of the individual element (IERi)																
		DGW 1	DGW 2	DGW 3	DGW 4	DGW 5	DGW 6	DGW 7	DGW 8	DGW 9	DGW 10	DGW 11	DGW 12	DGW 13	DGW 14	DGW 15	DGW 16	DGW 17
BOD	ppm	0.0	13.5	28.4	14.5	3.0	41.7	12.6	11.1	25.2	0.0	0.0	0.0	0.0	0.0	0.0	19.9	0.0
COD	ppm	0.0	0.0	1.0	0.0	0.0	1.6	0.0	0.0	0.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Chloride	ppm	9.8	6.6	11.9	6.9	6.2	14.7	7.1	7.0	13.4	10.8	0.0	4.4	5.8	4.9	6.5	12.8	3.5
Iron	ppm	1.3	0.3	0.7	0.3	1.0	0.7	2.0	0.7	2.0	2.3	1.0	0.7	0.0	1.0	0.3	1.3	0.0
Lead	ppm	0.0	0.0	0.0	0.0	458.0	0.0	0.0	0.0	0.0	0.0	19.7	0.0	0.0	0.0	0.0	0.0	0.0
Nitrate	ppm	1.1	0.2	0.7	0.3	1.0	3.3	1.0		1.7	1.1	1.0	0.0	0.2	0.5	0.2	0.4	0.5
Nitrite	ppm	0.0	4.0	0.0	0.0	0.0	5.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.5
Sodium	ppm	4.1	2.3	4.9	2.6	2.3	5.6	2.6	2.5	5.1	4.0	2.4	1.5	2.1	1.8	2.3	4.8	1.2
Sulfate	ppm	3.0	1.1	4.8	1.3	1.1	5.0	1.2	1.1	4.4	3.0	1.0	0.6	0.9	0.7	0.9	4.1	0.7
IERi		19.3	28.0	52.4	25.9	472.6	78.1	26.5	22.4	52.5	21.2	25.1	7.2	9.0	8.9	10.2	43.3	7.4

APPENDIX B

ENVIRONMENTAL PROTECTION AGENCY STANDARD FOR DRINKING WATER (USEPA)

Table B-1: List of National Secondary Drinking Water Regulations

Contaminant	Secondary Standard
Aluminum	0.05 to 0.2 ppm
Chloride	250 ppm
Color	15 (color units)
Copper	1.0 ppm
Corrosivity	noncorrosive
Fluoride	2.0 ppm
Foaming Agents	0.5 ppm
Iron	0.3 ppm
Manganese	0.05 ppm
Odor	3 threshold odor number
pH	6.5-8.5
Silver	0.10 ppm
Sulfate	250 ppm
Total Dissolved Solids	500 ppm
Zinc	5 ppm

Table B-2: Drinking Water Regulations (Microorganisms)

Contaminant	MCLG[1] (ppm)[2]	MCL or TT[1] (ppm)[2]	Potential Health Effects from Long-Term Exposure Above the MCL (unless specified as short-term)	Sources of Contaminant in Drinking Water
Cryptosporidium	zero	TT [3]	Gastrointestinal illness (e.g., diarrhea, vomiting, cramps)	Human and animal fecal waste
Giardia lamblia	zero	TT[3]	Gastrointestinal illness (e.g., diarrhea, vomiting, cramps)	Human and animal fecal waste
Heterotrophic plate count	n/a	TT[3]	HPC has no health effects; it is an analytic method used to measure the variety of bacteria that are common in water. The lower the concentration of bacteria in drinking water, the better maintained the water system is.	HPC measures a range of bacteria that are naturally present in the environment
Legionella	zero	TT[3]	Legionnaire's Disease, a type of pneumonia	Found naturally in water; multiplies in heating systems
Total Coliforms (including fecal coliform and E. Coli)	zero	5.0%[4]	Not a health threat in itself; it is used to indicate whether other potentially harmful bacteria may be present[5]	Coliforms are naturally present in the environment; as well as feces; fecal coliforms and E. coli only come from human and animal fecal waste.
Turbidity	n/a	TT[3]	Turbidity is a measure of the cloudiness of water. It is used to indicate water quality and filtration effectiveness (e.g., whether disease-causing organisms are present). Higher turbidity levels are often associated with higher levels of disease-causing microorganisms such as viruses, parasites and some bacteria. These organisms can cause symptoms such as nausea, cramps, diarrhea, and associated headaches.	Soil runoff
Viruses (enteric)	zero	TT[3]	Gastrointestinal illness (e.g., diarrhea, vomiting, cramps)	Human and animal fecal waste

Table A-3 Drinking Water Regulations (Disinfection Byproduct)

Contaminant	MCLG[1] (ppm)[2]	MCL or TT[1] (ppm)[2]	Potential Health Effects from Long-Term Exposure Above the MCL (unless specified as short-term)	Sources of Contaminant in Drinking Water
Bromate	zero	0.010	Increased risk of cancer	Byproduct of drinking water disinfection
Chlorite	0.8	1.0	Anemia; infants & young children: nervous system effects	Byproduct of drinking water disinfection
Haloacetic acids (HAA5)	n/a[6]	0.060[7]	Increased risk of cancer	Byproduct of drinking water disinfection
Total Trihalomethanes (TTHMs)	--> n/a[6]	--> 0.080[7]	Liver, kidney or central nervous system problems; increased risk of cancer	Byproduct of drinking water disinfection

Table A-4 Drinking Water Regulations (Disinfectants)

Contaminant	MCLG[1] (ppm)[2]	MCL or TT[1] (ppm)[2]	Potential Health Effects from Long-Term Exposure Above the MCL (unless specified as short-term)	Sources of Contaminant in Drinking Water
Chloramines (as Cl_2)	MRDLG=4[1]	MRDL=4.0[1]	Eye/nose irritation; stomach discomfort, anemia	Water additive used to control microbes
Chlorine (as Cl_2)	MRDLG=4[1]	MRDL=4.0[1]	Eye/nose irritation; stomach discomfort	Water additive used to control microbes
Chlorine dioxide (as ClO_2)	MRDLG=0.8[1]	MRDL=0.8[1]	Anemia; infants & young children: nervous system effects	Water additive used to control microbes

Table A-5 : Drinking Water Regulations (Inorganic Chemicals)

Contaminant	MCLG[1] (ppm)[2]	MCL or TT[1] (ppm)[2]	Potential Health Effects from Long-Term Exposure Above the MCL (unless specified as short-term)	Sources of Contaminant in Drinking Water
Antimony	0.006	0.006	Increase in blood cholesterol; decrease in blood sugar	Discharge from petroleum refineries; fire retardants; ceramics; electronics; solder
Arsenic	0[7]	0.010 as of 01/23/06	Skin damage or problems with circulatory systems, and may have increased risk of getting cancer	Erosion of natural deposits; runoff from orchards, runoff from glass & electronicsproduction wastes
Asbestos (fiber >10 micrometers)	7 million fibers per liter	7 MFL	Increased risk of developing benign intestinal polyps	Decay of asbestos cement in water mains; erosion of natural deposits
Barium	2	2	Increase in blood pressure	Discharge of drilling wastes; discharge from metal refineries; erosion of natural deposits
Beryllium	0.004	0.004	Intestinal lesions	Discharge from metal refineries and coal-burning factories; discharge from electrical, aerospace, and defense industries
Cadmium	0.005	0.005	Kidney damage	Corrosion of galvanized pipes; erosion of natural deposits; discharge from metal refineries; runoff from waste batteries and paints
Chromium (total)	0.1	0.1	Allergic dermatitis	Discharge from steel and pulp mills; erosion of natural deposits
Copper	1.3	TT[7]; Action Level=1.3	Short term exposure: Gastrointestinal distress Long term exposure: Liver or kidney damage People with Wilson's Disease should consult their personal doctor if the amount of copper in their water exceeds the action level	Corrosion of household plumbing systems; erosion of natural deposits
Cyanide (as free cyanide)	0.2	0.2	Nerve damage or thyroid problems	Discharge from steel/metal factories; discharge from plastic and fertilizer factories
Fluoride	4.0	4.0	Bone disease (pain and tenderness of the bones); Children may get mottled teeth	Water additive which promotes strong teeth; erosion of natural deposits; discharge from fertilizer and aluminum factories
Lead	zero	TT[7]; Action Level=0.015	Infants and children: Delays in physical or mental	Corrosion of household plumbing systems; erosion of

			development; children could show slight deficits in attention span and learning abilities Adults: Kidney problems; high blood pressure	natural deposits
Mercury (inorganic)	0.002	0.002	Kidney damage	Erosion of natural deposits; discharge from refineries and factories; runoff from landfills and croplands
Nitrate (measured as Nitrogen)	10	10	Infants below the age of six months who drink water containing nitrate in excess of the MCL could become seriously ill and, if untreated, may die. Symptoms include shortness of breath and blue-baby syndrome.	Runoff from fertilizer use; leaching from septic tanks, sewage; erosion of natural deposits
Nitrite (measured as Nitrogen)	1	1	Infants below the age of six months who drink water containing nitrite in excess of the MCL could become seriously ill and, if untreated, may die. Symptoms include shortness of breath and blue-baby syndrome.	Runoff from fertilizer use; leaching from septic tanks, sewage; erosion of natural deposits
Selenium	0.05	0.05	Hair or fingernail loss; numbness in fingers or toes; circulatory problems	Discharge from petroleum refineries; erosion of natural deposits; discharge from mines

Table A-6 Drinking Water Regulations (Organic Chemicals)

Contaminant	MCLG[1] (ppm)[2]	MCL or TT[1] (ppm)[2]	Potential Health Effects from Long-Term Exposure Above the MCL (unless specified as short-term)	Sources of Contaminant in Drinking Water
Acrylamide	zero	TT[8]	Nervous system or blood problems; increased risk of cancer	Added to water during sewage/wastewater treatment
Alachlor	zero	0.002	Eye, liver, kidney or spleen problems; anemia; increased risk of cancer	Runoff from herbicide used on row crops
Atrazine	0.003	0.003	Cardiovascular system or reproductive problems	Runoff from herbicide used on row crops
Benzene	zero	0.005	Anemia; decrease in blood platelets; increased risk of cancer	Discharge from factories; leaching from gas storage tanks and landfills
Benzo(a)pyrene (PAHs)	zero	0.0002	Reproductive difficulties; increased risk of cancer	Leaching from linings of water storage tanks and distribution lines
Carbofuran	0.04	0.04	Problems with blood, nervous system, or reproductive system	Leaching of soil fumigant used on rice and alfalfa
Carbon tetrachloride	zero	0.005	Liver problems; increased risk of cancer	Discharge from chemical plants and other industrial activities
Chlordane	zero	0.002	Liver or nervous system problems; increased risk of cancer	Residue of banned termiticide
Chlorobenzene	0.1	0.1	Liver or kidney problems	Discharge from chemical and agricultural chemical factories
2,4-D	0.07	0.07	Kidney, liver, or adrenal gland problems	Runoff from herbicide used on row crops
Dalapon	0.2	0.2	Minor kidney changes	Runoff from herbicide used on rights of way
1,2-Dibromo-3-chloropropane (DBCP)	zero	0.0002	Reproductive difficulties; increased risk of cancer	Runoff/leaching from soil fumigant used on soybeans, cotton, pineapples, and orchards
o-Dichlorobenzene	0.6	0.6	Liver, kidney, or circulatory system problems	Discharge from industrial chemical factories
p-Dichlorobenzene	0.075	0.075	Anemia; liver, kidney or spleen damage; changes in blood	Discharge from industrial chemical factories
1,2-Dichloroethane	zero	0.005	Increased risk of cancer	Discharge from industrial chemical factories
1,1-Dichloroethylene	0.007	0.007	Liver problems	Discharge from industrial chemical factories
cis-1,2-Dichloroethylene	0.07	0.07	Liver problems	Discharge from industrial chemical factories
trans-1,2-Dichloroethylene	0.1	0.1	Liver problems	Discharge from industrial chemical factories
Dichloromethane	zero	0.005	Liver problems; increased risk of cancer	Discharge from drug and chemical factories
1,2-Dichloropropane	zero	0.005	Increased risk of cancer	Discharge from industrial chemical factories
Di(2-ethylhexyl) adipate	0.4	0.4	Weight loss, liver problems, or possible reproductive difficulties.	Discharge from chemical factories

Di(2-ethylhexyl) phthalate	zero	0.006	Reproductive difficulties; liver problems; increased risk of cancer	Discharge from rubber and chemical factories
Dinoseb	0.007	0.007	Reproductive difficulties	Runoff from herbicide used on soybeans and vegetables
Dioxin (2,3,7,8-TCDD)	zero	0.00000003	Reproductive difficulties; increased risk of cancer	Emissions from waste incineration and other combustion; discharge from chemical factories
Diquat	0.02	0.02	Cataracts	Runoff from herbicide use
Endothall	0.1	0.1	Stomach and intestinal problems	Runoff from herbicide use
Endrin	0.002	0.002	Liver problems	Residue of banned insecticide
Epichlorohydrin	zero	TT[8]	Increased cancer risk, and over a long period of time, stomach problems	Discharge from industrial chemical factories; an impurity of some water treatment chemicals
Ethylbenzene	0.7	0.7	Liver or kidneys problems	Discharge from petroleum refineries
Ethylene dibromide	zero	0.00005	Problems with liver, stomach, reproductive system, or kidneys; increased risk of cancer	Discharge from petroleum refineries
Glyphosate	0.7	0.7	Kidney problems; reproductive difficulties	Runoff from herbicide use
Heptachlor	zero	0.0004	Liver damage; increased risk of cancer	Residue of banned termiticide
Heptachlor epoxide	zero	0.0002	Liver damage; increased risk of cancer	Breakdown of heptachlor
Hexachlorobenzene	zero	0.001	Liver or kidney problems; reproductive difficulties; increased risk of cancer	Discharge from metal refineries and agricultural chemical factories
Hexachlorocyclopentadiene	0.05	0.05	Kidney or stomach problems	Discharge from chemical factories
Lindane	0.0002	0.0002	Liver or kidney problems	Runoff/leaching from insecticide used on cattle, lumber, gardens
Methoxychlor	0.04	0.04	Reproductive difficulties	Runoff/leaching from insecticide used on fruits, vegetables, alfalfa, livestock
Oxamyl (Vydate)	0.2	0.2	Slight nervous system effects	Runoff/leaching from insecticide used on apples, potatoes, and tomatoes
Polychlorinated biphenyls (PCBs)	zero	0.0005	Skin changes; thymus gland problems; immune deficiencies; reproductive or nervous system difficulties; increased risk of cancer	Runoff from landfills; discharge of waste chemicals
Pentachlorophenol	zero	0.001	Liver or kidney problems; increased cancer risk	Discharge from wood preserving factories
Picloram	0.5	0.5	Liver problems	Herbicide runoff
Simazine	0.004	0.004	Problems with blood	Herbicide runoff
Styrene	0.1	0.1	Liver, kidney, or circulatory system problems	Discharge from rubber and plastic factories; leaching from landfills
Tetrachloroethylene	zero	0.005	Liver problems; increased risk of cancer	Discharge from factories and dry cleaners
Toluene	1	1	Nervous system, kidney, or liver problems	Discharge from petroleum factories

Toxaphene	zero	0.003	Kidney, liver, or thyroid problems; increased risk of cancer	Runoff/leaching from insecticide used on cotton and cattle
2,4,5-TP (Silvex)	0.05	0.05	Liver problems	Residue of banned herbicide
1,2,4-Trichlorobenzene	0.07	0.07	Changes in adrenal glands	Discharge from textile finishing factories
1,1,1-Trichloroethane	0.20	0.2	Liver, nervous system, or circulatory problems	Discharge from metal degreasing sites and other factories
1,1,2-Trichloroethane	0.003	0.005	Liver, kidney, or immune system problems	Discharge from industrial chemical factories
Trichloroethylene	zero	0.005	Liver problems; increased risk of cancer	Discharge from metal degreasing sites and other factories
Vinyl chloride	zero	0.002	Increased risk of cancer	Leaching from PVC pipes; discharge from plastic factories
Xylenes (total)	10	10	Nervous system damage	Discharge from petroleum factories; discharge from chemical factories

APPENDIX C

PICTURES FROM THE STUDY AREA

Figure : Sewage flooding in Turkia Reference: Alyaum news paper, 2007,
No. 12353

Figure 2 : Sewage flooding in Arabiaiah, Reference: Alyaum newspaper, 2007, No. 12309

Figure 3 : Waste disposal in Turkia

Figure 4 : waste disposal in Turkia

Figure 6 : waste disposal in Turkia

Figure 7 : Dumping in Turkia, Reference: Alyaum newspaper, 2007, No.12442

Figure 8 : waste disposal in Turkia

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